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PROCEEDINGS

OF THE

ENGINEERS' CLUB

OF

PHILADELPHIA.

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VOL. X.

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I.

THE DISTRIBUTION OF PRESSURE IN BEARINGS.

By CARL G. BARTH, Active Member of the Club.

Read October 1, 1892.

THE distribution of pressure in bearings is primarily a matter of fitting, and in bearings, which are fixed or move but little, the distribution of pressure can be conjectured only from the care and skill employed. This may be said of all bearings when new, but in running bearings the conditions must change, as wear takes place, until a certain distribution is reached as the final and natural result. What this may be will depend on the correlations of pressure, velocity, friction and wear, on which it is very difficult to obtain definite and reliable data; but, for the purpose of theoretical investigation, certain relations may be assumed as approximately correct, which are founded upon reason and experience.

The friction in running bearings was originally determined on the assumption of uniform pressure between the sliding surfaces, but the consideration of wear rendered this assumption untenable, and more recent investigators have proceeded on the theory of uniform wear.

When this theory was first brought to my attention a few years ago by our fellow-member, Mr. Wilfred Lewis, I became so thor-

oughly interested in it as to make a series of original investigations, some of which were anticipated in the German handbook, "Hütte," and possibly elsewhere; but as a great deal of the matter has not been found in print and may be new to the profession generally, it has been thought that a general review of the subject would be of interest.

The ordinary vertical step bearing will serve as a good illustration of what is understood by the theory of uniform wear.

Referring to Fig. 1, it is evident that the pressure between the end of the shaft and its step, due to the load P, will eventually be so distributed over these surfaces that the wear can take place to the same extent all over, allowing the shaft to sink into the bearing a minute distance w for each revolution.

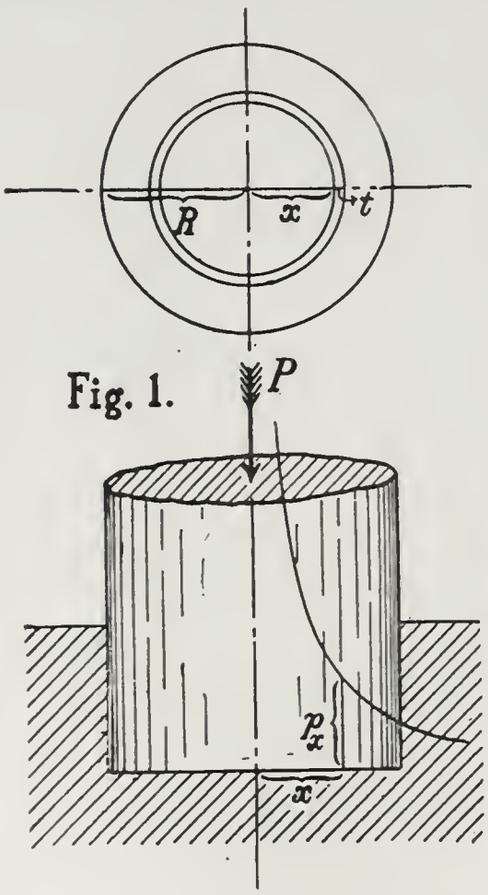


Fig. 1.

On the approximately correct supposition that the amount of wear between two rubbing surfaces is proportional to the amount of frictional work done, and on the further supposition that the coefficient of friction ϕ is the same at all points of the step, we can now determine in what manner the intensity of pressure p_x varies with the distance x from the center of the step.

If we consider an indefinitely narrow annulus of the step, of radius x and width t, the total pressure on the same is $p_x\ 2x\pi\ t$, and the amount of frictional work per revolution, due to this pressure, will be $\phi\ p_x\ 2x\pi\ t\ 2x\pi$. The amount of material worn from the rubbing surfaces, due to this work, is $2x\pi\ t\ w$, and hence, as

$$\text{Wear} = \text{frictional work} \times \text{a constant},$$

$$2x\pi\ t\ w = \phi\ p_x\ 2x\pi\ t\ 2x\pi\ C. \quad \text{(Equation 1.)}$$

This equation now gives $p_x\ 2x\pi\ t = \dfrac{t\ w}{\phi\ C}$ which shows that the total pressure on an indefinitely narrow annulus of the step is

independent of its own radius; and hence, if we suppose the step entirely divided into such annuli of equal widths, they must each support the same share of the pressure P, which accordingly, so far as the moment of friction due to that pressure goes, may be considered as concentrated on an indefinitely narrow annulus whose radius equals half the radius of the step.

The moment of friction thus becomes $\phi\, P\, \frac{1}{2}\, R$; it being generally figured at $\phi\, P\, \frac{2}{3}\, R$, as deduced on the evidently incorrect supposition that the pressure is uniformly distributed throughout the step.

For an annular step bearing of outside radius R and inside radius r, the moment of friction will likewise be $\phi\, P\, \frac{1}{2}\, (R + r)$ as against $\phi\, P\, \frac{2}{3}\, \frac{R^3 - r^3}{R - r}$, deduced on the supposition of uniform pressure.

(Equation 1) also gives $p_x = \frac{w}{2\pi\, \phi\, C x}$, which shows that the intensity of pressure varies inversely as the distance from the center, and that it accordingly is ∞ at the center itself, where a tendency to a crushing effect must exist, there being no sliding at that point. For this reason it is probably good practice to make a step bearing annular.

In order to determine the maximum intensity of pressure in an annular step bearing, suppose the bearing surface divided into an indefinitely large number n of annuli of equal widths, when the width of each will become $\frac{R - r}{n}$. But, according to the above, each annulus will carry just $\frac{1}{n}$ of the total pressure P, and the pressure on the annulus of the radius x becomes:

$$p_x\, 2x\pi\, \frac{R - r}{n} = \frac{P}{n}.$$

This equation gives $p_x = \frac{P}{2x\pi\, (R - r)}$, which for $x = r$ becomes the maximum $\frac{P}{2r\pi\, (R - r)}$.

We will now pass on to the consideration of an ordinary journal bearing as represented by Fig. 2, where P is the pressure

forcing the shaft into the bearing and supposed to be exerted at its middle, a condition of affairs that should always be aimed at in placing and proportioning bearings, but which, as will be shown further on in this discussion, is a thing generally neglected by the average designer.

Fig. 2.

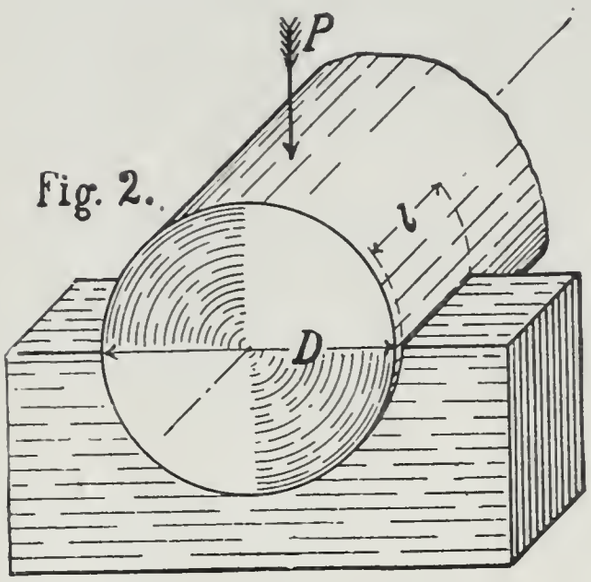
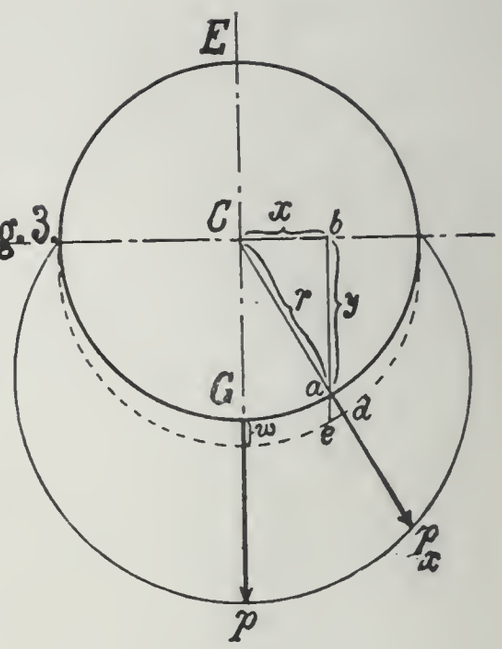


Fig. 3.



Referring to Fig. 3, $w = a\,e$ is again supposed to represent the minute wear in the bearing, in the direction of the pressure, for each revolution of the shaft; $w_x = a\,d$, the same wear measured in a normal direction to the shaft along a line in the bearing at the distance x from the vertical center line $E\,G$. p represents the maximum intensity of pressure in the bearing, and p_x the intensity of pressure normal to the shaft along the line referred to.

The small figure $a\,d\,e$ can, without any perceptible error, be considered as a triangle similar to the triangle $a\,b\,C$, and we get:

$$a\,e : a\,d = a\,C : a\,b \text{ or}$$

$$w : w_x = r : y,$$

but as the amount of sliding between the shaft and the bearing in this case is everywhere the same, the intensity of normal pressure p_x must be directly proportional to the amount of normal wear w_x, and we also get:

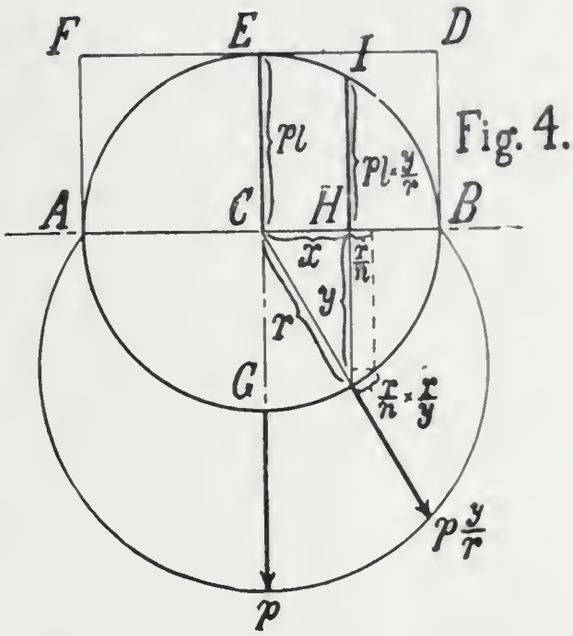
$$p : p_x = w : w_x = r : y \text{ and hence}$$

$$p_x = p\,\frac{y}{r}.$$

That is, the intensity of normal pressure varies directly as the

ordinate y, and can therefore be represented by the same, as done in the figure.

If we now suppose the radius $C\,B = r$ of the bearing (Fig. 4) divided into an indefinitely large number n of equal parts, each division becomes $\frac{r}{n}$, which may be considered as the horizontal projection of the width of an element of the bearing, at a distance x from the vertical center line $E\,G$, and whose width is $\frac{r}{n}\,\frac{r}{y}$. The normal pressure on this element becomes $\left(p\,\frac{y}{r}\right)\left(\frac{r}{n}\,\frac{r}{y}\right)\,l$ $= p\,\frac{r}{n}\,l$, and accordingly the total sum of the normal pressures on all the elements of the bearing will be $\left(p\,\frac{r}{n}\,l\right)\,2n = p\,D\,l$. That is, the total sum of the normal pressures on all the elements of the bearing, and which we will call N, is equivalent to a pressure uniformly distributed over the horizontal projection of the bearing, and whose intensity is the maximum intensity of pressure in the bearing. If we, therefore, let the radius $C\,E$ represent $p\,l$, the rectangle $A\,B\,D\,F$ will represent $N = p\,D\,l$.



The vertical component of the normal pressure $p\,\frac{r}{n}\,l$ on the element above considered will be $\left(p\,\frac{r}{n}\,l\right)\,\frac{y}{r} = \left(p\,\frac{y}{r}\right)\left(\frac{r}{n}\,l\right)$, that is, equivalent to the intensity of normal pressure on the element acting on its horizontal projection. Hence the total sum of the vertical components of the normal pressures on all the elements of the bearing, and which sum we will call V, will be equivalent to a pressure so distributed over the total horizontal projection of the bearing, that the intensity of pressure at the distance x from the center varies as the corresponding ordinate y,

this intensity being at the center equal to the maximum intensity p in the bearing:

If we, as above, let the radius $C\ E$ represent $p\ l$, the ordinate $H\ I$ will represent $p\ l \frac{y}{r}$ and the semicircle $A\ B\ E$ the pressure V, and hence, as the area of this is $\frac{r^2 \pi}{2}$ and the area of the rectangle $A\ B\ D\ F$ is $2r^2$, we get:

$$V : N = \frac{r^2 \pi}{2} : 2r^2 \text{ and}$$

$$V = \frac{\pi}{4} N = \frac{\pi}{4} p\ D\ l.$$

But V must equal the pressure P forcing the shaft into the bearing, and so we get:

$$P = \frac{\pi}{4} p\ D\ l, \text{ which gives } p = \frac{4}{\pi} \frac{P}{D\ l}.$$

That is, the maximum intensity of pressure in an ordinary journal bearing is not equal to the pressure divided by the projection of the bearing, which it is commonly figured at, but it is $\frac{4}{\pi}$ times that amount. N also becomes $\frac{4}{\pi} P$.

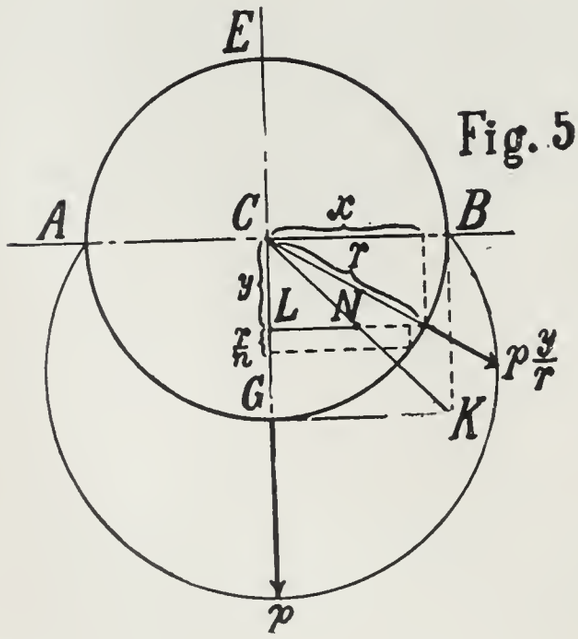


Fig. 5.

If again we suppose the radius $C\ G = r$, Fig. 5, divided into the indefinitely large number n of equal parts, each division will again be $\frac{r}{n}$, and which may be considered as the vertical projection of the width of an element of the bearing at a distance y below the horizontal center line $A\ B$, and whose width is $\frac{r}{n} \frac{r}{x}$. The normal pressure on this element becomes $\left(p \frac{y}{r}\right) \left(\frac{r}{n} \frac{r}{x}\right) l = p \left(\frac{r}{n} l\right) \frac{y}{x}$. The horizontal component of this pressure will be $p \left(\frac{r}{n} l\right) \frac{y}{x} \frac{x}{r} = \left(p \frac{y}{r}\right) \left(\frac{r}{n} l\right)$, that is,

equivalent to the intensity of normal pressure acting on the vertical projection of the element. Hence the total sum of the horizontal components of the normal pressure on all the elements in each half of the bearing, and which sum we will call H, will be equivalent to a pressure so distributed over the total vertical projection $r\ l$ of the bearing, that the intensity of pressure varies directly as the distance y from the center, and being for $y = r$ equal to the maximum intensity of pressure p in the bearing. If we, therefore, let $G\ K = r$ represent $p\ l$, $L\ N = y$ will represent $p\ l \frac{y}{r}$, and the triangle $C\ G\ K$ will represent the pressure H, which accordingly becomes

$$H = \tfrac{1}{2}\, p\, r\, l = \frac{1}{\pi}\, P.$$

The center of gravity of the quadrant $A\ C\ E$, Fig. 6, which quadrant, according to what we have seen, may represent the total vertical pressure $\frac{1}{2}V$ in that half of the bearing, being at $x = \frac{4}{3\pi}\, r$, and the center of gravity of the triangle $C\ G\ K$, representing the horizontal pressure H, being at $y = \frac{2}{3}\, r$, we can now find the direction and value of the resultant pressure, which we will call N_1, in each half of the bearing.

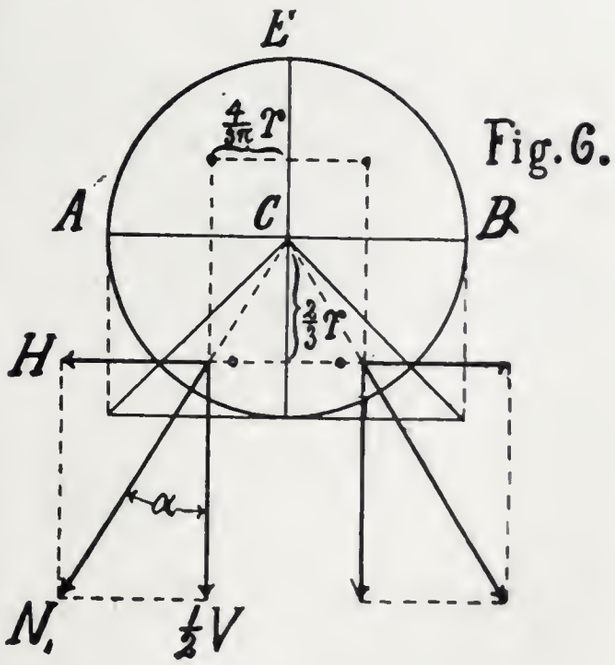


Fig. 6.

We get tang. $a = \dfrac{H}{\frac{1}{2}V} = \dfrac{\frac{1}{\pi}P}{\frac{1}{2}P} = \dfrac{2}{\pi}$, which is also $= \dfrac{\frac{4}{3\pi}r}{\frac{2}{3}r}$ and from which it follows that N_1 passes through the center of the bearing. This might, of course, be anticipated, as N_1 even more directly is the resultant of the normal pressures on all the elements in each half of the bearing. Since

$$\text{tang. } a = \frac{2}{\pi},\ a = 32^\circ\ 28\tfrac{1}{2}'$$

$$N_1 = \sqrt{(\tfrac{1}{2}V)^2 + H^2} = \sqrt{(\tfrac{1}{2}P)^2 + \left(\frac{1}{\pi}P\right)^2} = \frac{\sqrt{\pi^2+4}}{2\pi}. \quad P = .58594\,P.$$

These expressions for the directions and values of the resultant pressures in a bearing may be made use of to determine what the bending moment will become on a short beam forming the bearing of a shaft, when this shall have been well run in under its maximum pressure.

In connection with Fig. 4, the normal pressure on an element of the bearing whose horizontal projection is $\frac{r}{n}\,l$, was found to be $p\left(\frac{r}{n}\,l\right)$ and its vertical component to be $p\,\frac{y}{r}\left(\frac{r}{n}\,l\right)$.

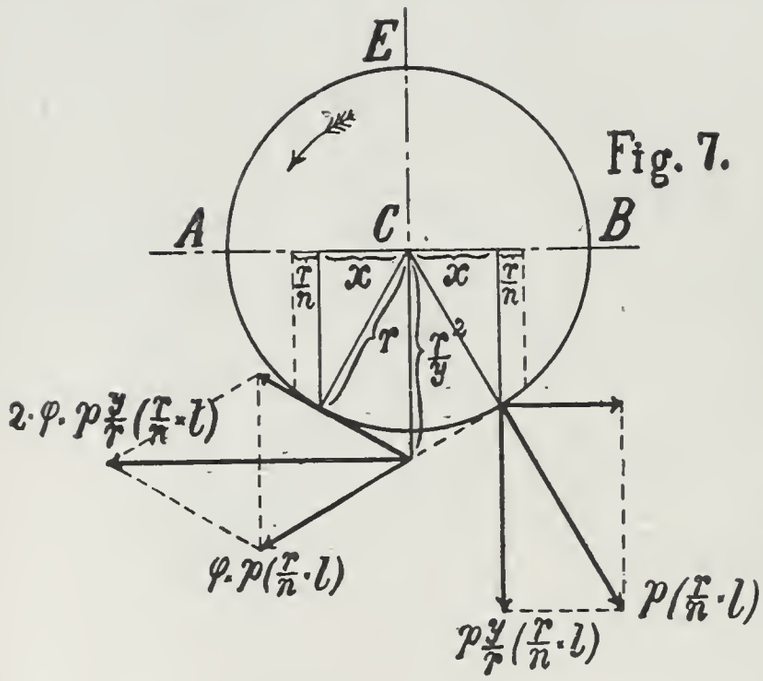


Fig. 7.

If we now suppose the shaft, Fig. 7, to revolve in the direction indicated by the arrow, this normal pressure will give rise to a friction, which may be treated as a live force acting tangent to the shaft and opposite to the direction of motion, and whose value will be $\phi\,p\left(\frac{r}{n}\,l\right)$. If we combine the frictions on two elements at equal distances x on each side of the vertical center line $E\,G$, into a single force, their resultant will be $2\,\phi\,p\,\frac{y}{r}\left(\frac{r}{n}\,l\right)$, and which expression is the same as the one for the vertical component of the normal pressure on each of the two elements $\times\,2\,\phi$, and hence the sum of the combined frictions on both sides of the vertical center line will equal the total vertical pressure in the bearing $\times\,\phi$, or $= \phi\,V = \phi\,P$.

But the lever arm at which the resultant $2\,\phi\,p\,\frac{y}{r}\left(\frac{r}{n}\,l\right)$ acts is $\frac{r^2}{y}$, and hence the moment of this resultant becomes

$$2\,\phi\,p\,\frac{y}{r}\left(\frac{r}{n}\,l\right)\frac{r^2}{y} = 2\,\phi\,p\,r\left(\frac{r}{n}\,l\right),$$

and the sum of the moments of friction of all the elements of the bearing will be

$$2\,\phi\,p\,r\left(\frac{r}{n}\,l\right)n = 2\,\phi\,\frac{\frac{4}{\pi}\,P}{D\,l}\,r^2\,l = \phi\,\frac{4}{\pi}\,P\,r.$$

This expression for the moment of friction we can also derive more directly, as it is evident that the total amount of friction is equal to the total amount of normal pressure $\times\,\phi$, that is, $= \phi\,N = \phi\,\frac{4}{\pi}\,P$, and also that this is acting on the radius as lever arm.

Dividing the moment of friction $\phi\,\frac{4}{\pi}\,P\,r$ by the expression derived above for the resultant force $\phi\,P$ of friction, we get $\frac{4}{\pi}\,r$ as the arm on which this resultant force of friction may be considered to act.

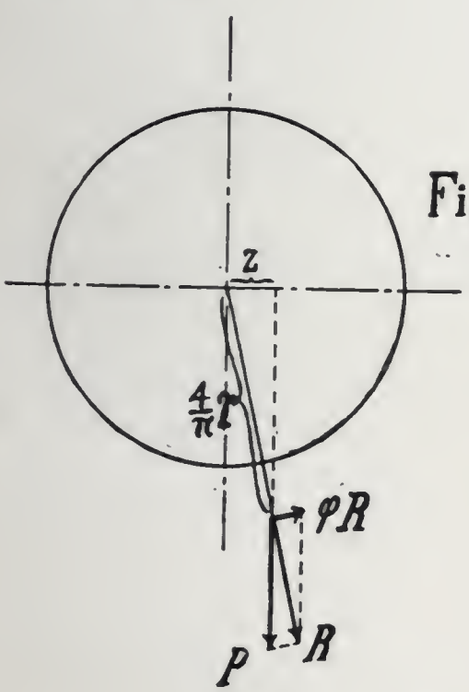


Fig. 8.

We are now able to determine the exact distance z from the center of a shaft, at which a force P must be applied, that it may just overcome the friction it gives rise to in the bearing. R (Fig. 8) is the resultant pressure, the friction $\phi\,R$ due to which acts perpendicular to it at the distance $\frac{4}{\pi}\,r$ from the center, and hence we have for equilibrium:

$P\,z = \phi\,R\,\frac{4}{\pi}\,r$, but $R^2 + (\phi\,R)^2 = P^2$

and hence $R = \frac{P}{\sqrt{1+\phi^2}}$, which substituted above gives

$$z = \phi\,\frac{4}{\pi}\,\frac{r}{\sqrt{1+\phi^2}}.$$

This value of z again enables us to determine the exact pressure P (Fig. 9) required on the arm p to just overcome the load L on the arm l, as the resultant of P and L (here $P + L$) must fall towards P at the distance z from the center. Hence

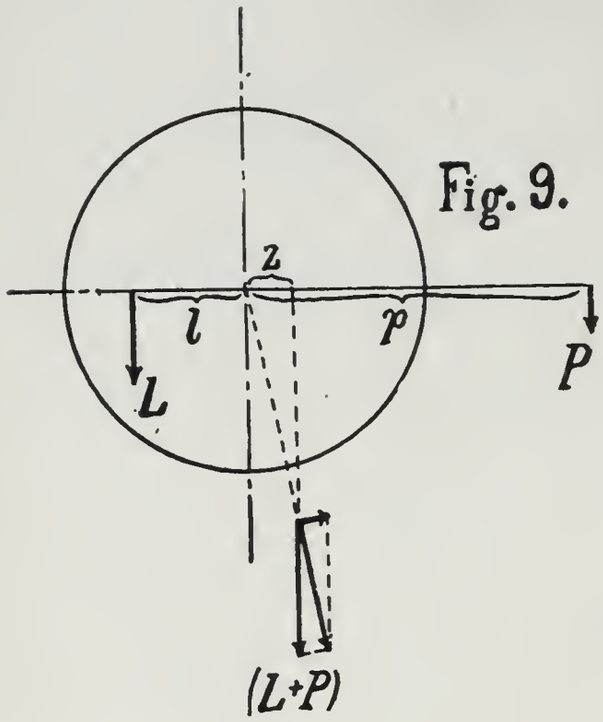


Fig. 9.

$$P(p - z) = L(l + z), \text{ or}$$

$$P = L\frac{l+z}{p-z} = L\frac{l + \phi\frac{4}{\pi}\frac{r}{\sqrt{1+\phi^2}}}{p - \phi\frac{4}{\pi}\frac{r}{\sqrt{1+\phi^2}}}$$

In most cases $\sqrt{1 + \phi^2}$ can without much error be taken $= 1$, and this expression be simplified to

$$P = L\frac{l + \phi\frac{4}{\pi}r}{p - \phi\frac{4}{\pi}r.}$$

P is ordinarily figured $= L\frac{l + \phi_1 r}{p - \phi_1 r,}$ and ϕ_1, as found in tables for journal frictions is probably in most cases deduced from experiments by means of this formula.

From this it appears that the coefficient ϕ_1, as given in tables for journal frictions, is in reality the true coefficient of friction ϕ multiplied by $\frac{4}{\pi}$, this factor $\frac{4}{\pi}$ being ordinarily figured in with the coefficient of friction instead of with the normal pressure producing the friction at the end of the radius, or instead of in the lever arm for the resultant force of friction, according as we choose to look at it.

Having investigated the distribution of pressure in bearings as the natural result of wear, the proportions for bearings and their proper location remain to be considered.

A little inspection of machinery generally discloses the fact

that this is a matter to which proper attention is rarely given, the result being that the durability of bearings and shafts is far less than it might be if a moderate amount of care were exercised. We will consider the matter in connection with a few examples.

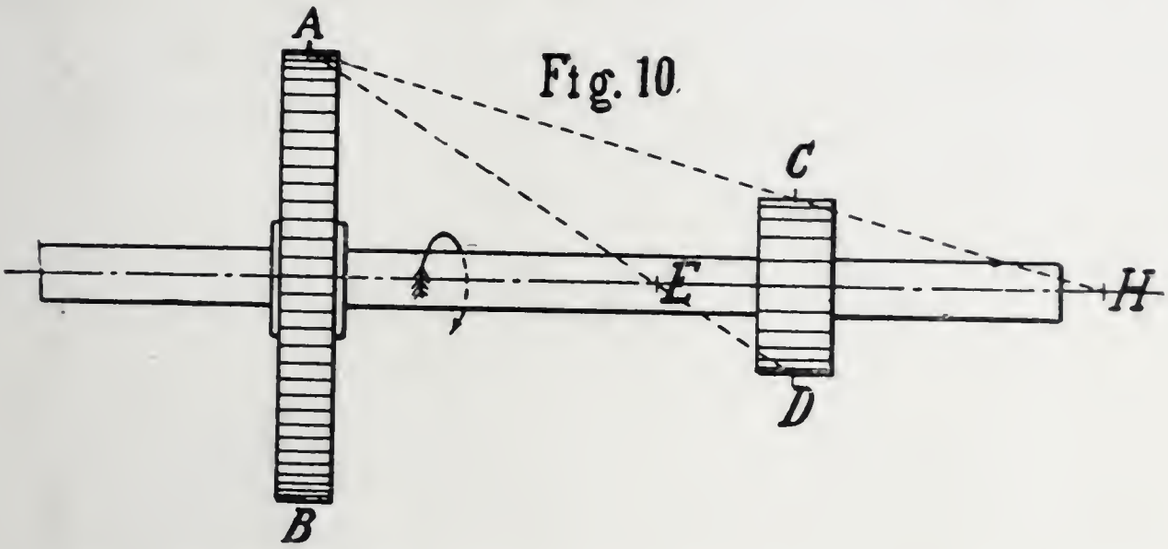


Fig. 10.

In Fig. 10 we will suppose the shaft to revolve in the direction indicated by the arrow, due to a pressure perpendicular to the paper at *A* on the circumference of the wheel *A B*, and that it transmits a correspondingly greater pressure at *D* on the circumference of the smaller wheel *C D*.

The reaction at *D* is then evidently a pressure acting in the same direction as the pressure received at *A*, and the resultant pressure on the shaft will be the sum of these two parallel pressures, and its point of application at *E*. The question then is where to put the bearings to support this shaft against displacement by this resultant. If we place the one of two bearings of

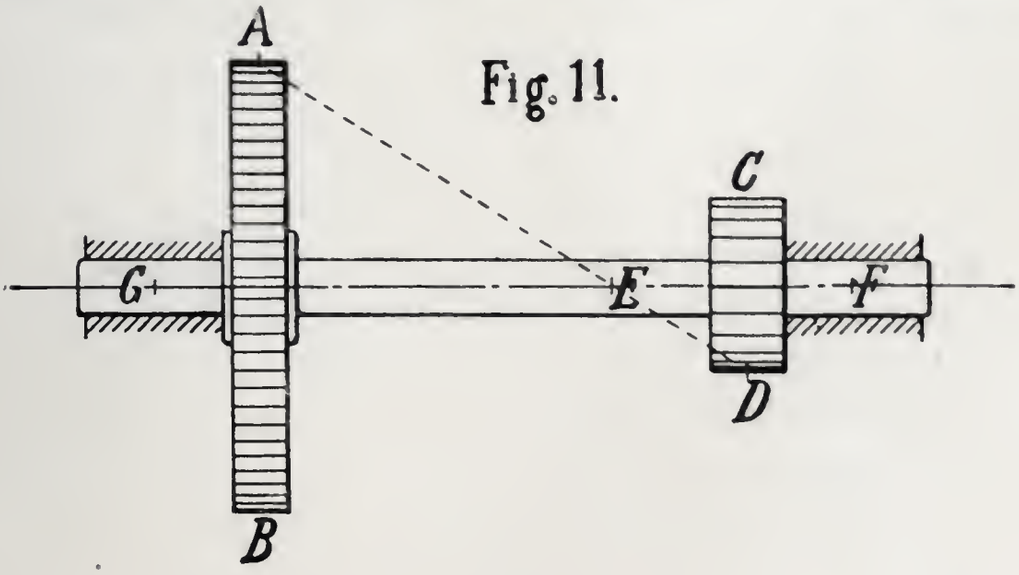


Fig. 11.

equal lengths at F, to the right of the wheel $C\,D$, and the other at G, to the left of $A\,B$, as in Fig. 11, the resultant pressure on the shaft at E will at first tend to divide itself between them inversely as the distances $F\,E$ and $G\,E$. The bearing at F wil thus receive a heavier pressure than the one at G, and accordingly wear more rapidly than this latter, this resulting in an angular displacement of the shaft, and in an unequal distribution of the pressure in both bearings.

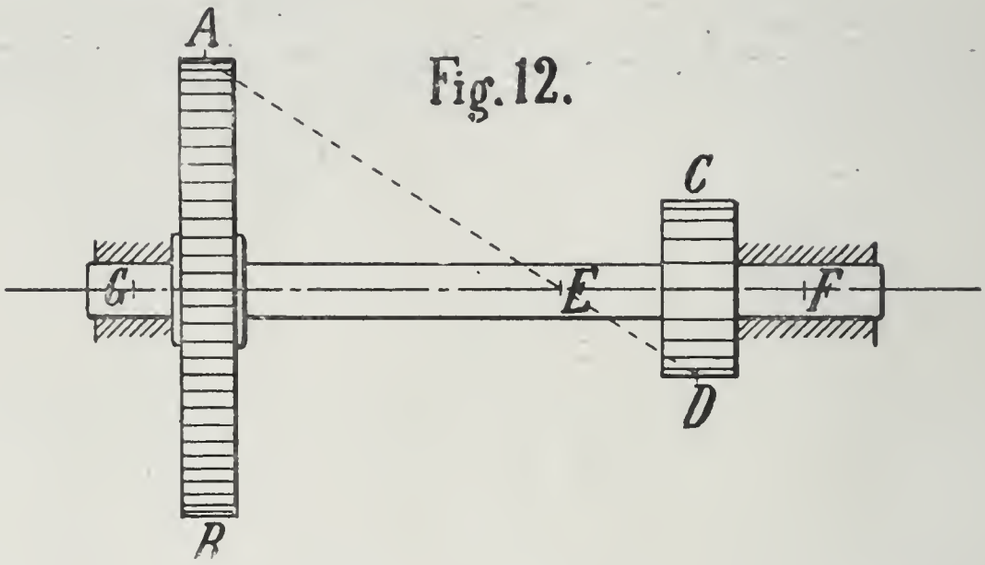


Fig. 12.

For obvious reasons this angular displacement and unequal distribution of pressure are the very things to be as far as possible avoided, and in this case this is accomplished by making, as shown in Fig. 12, the lengths of the two bearings proportional to the respective pressures supported by them, that is, inversely proportional to their respective distances from the point of application E of the resultant pressure on the shaft.

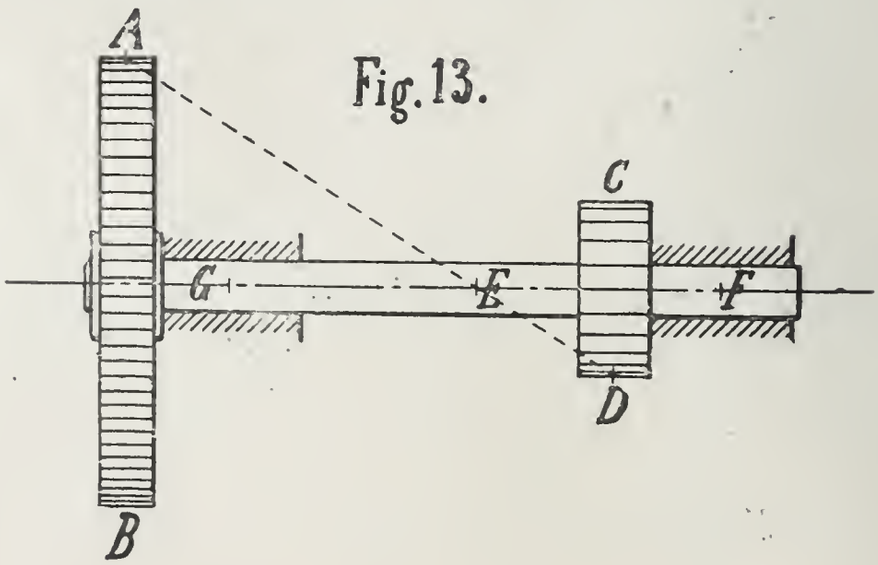


Fig. 13.

Should we, however, for good reasons, prefer to make the bearings of the same length, we can still avoid the angular displacement of the shaft by placing them, as in Fig. 13, equidistant about the point *E*. The bearings will then each receive just one-half of the resultant pressure on the shaft uniformly distributed, and wear away equally rapidly, thus retaining the shaft parallel to its original position.

But let us now suppose the wheel *C D* (Fig. 10) to transmit its pressure at *C* instead of at *D*, and the conditions will prove themselves to be entirely different. The reaction at *C* is now a pressure acting in the opposite direction to the pressure at *A*, and the resultant of these two pressures is their difference applied at the point *H*.

In a case of this kind it is hardly practicable to support the shaft by bearings on both sides of the resultant pressure at *H*, and thus entirely obviate an angular displacement of the shaft, and our efforts must therefore be limited to reducing this to a minimum by placing the bearings, as in Fig. 14, as far apart as possible, with the one as near the point *H* as is consistent with space and the stiffness of the shaft.

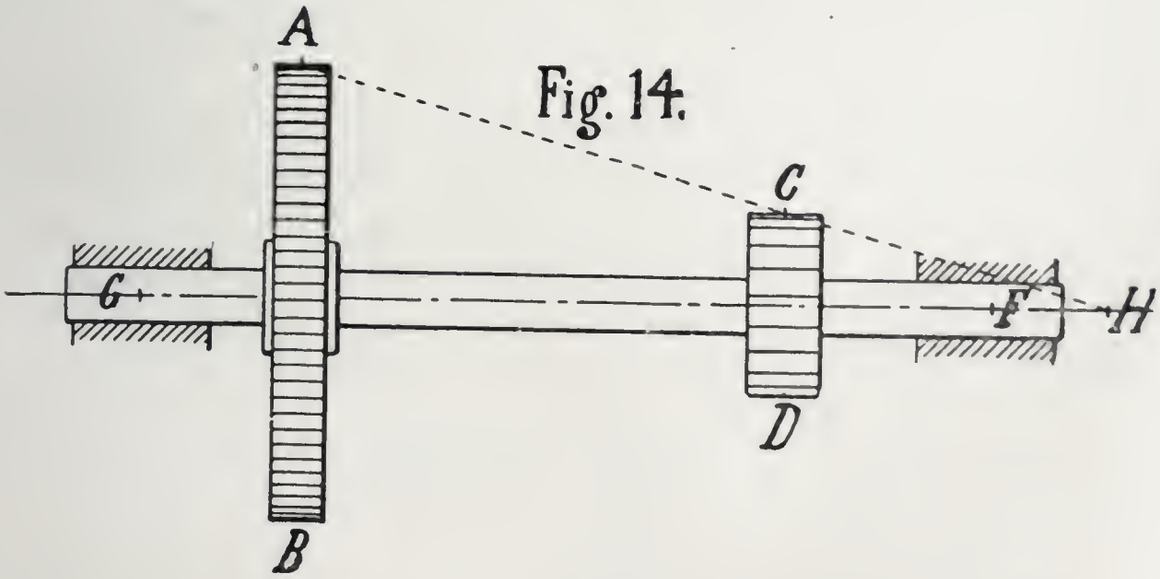


Fig. 14.

In a case like this, though it is well to make the bearing at *F* as long as possible, no advantage is obtained by making the one at *C* any shorter, as on account of the pressure acting in opposite directions in the two bearings, the angular displacement of the shaft will be diminished by additional restraint at either of them.

We will now easily see the absurdity of the rule which many

machine designers have for the minimum length allowable for the bearing in cases as the one illustrated by Fig. 15, as the value of the bearing entirely depends on whether the pressures are transmitted as across from *A* to *D*, or as from *A* to *C*. In the

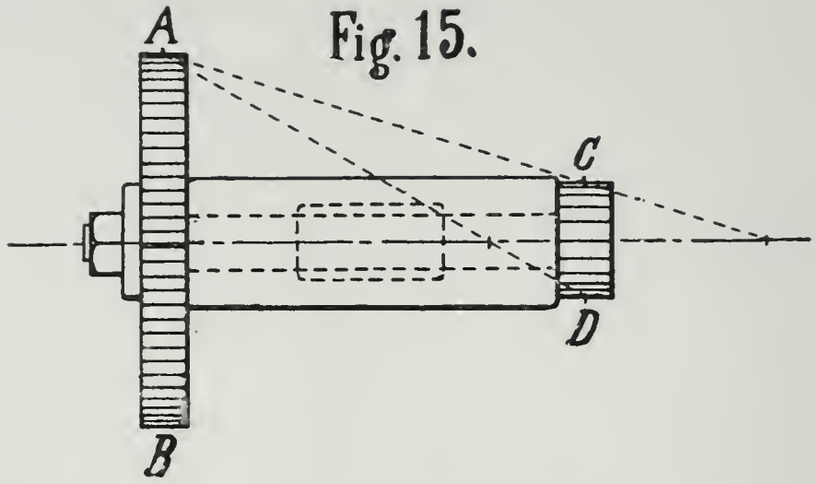


Fig. 15.

former case the shaft is thrown against the whole surface of the bearing, and can even be made to wear parallel to itself by a proper location of the chamber, whereas in the latter case it is thrown against the opposite edges only of the mouths of the bearing, and as a consequence considerable angular displacement must take place before appreciable wearing surface will be produced.

A mistake frequently discovered on even first-class machinery is the lengthening of the hub of a gear-wheel or pulley running loose on a shaft or a stud, to one side of the center, if it is necessarily limited to the other by existing circumstances, thus producing a condition of affairs as the one represented by Fig. 16. The

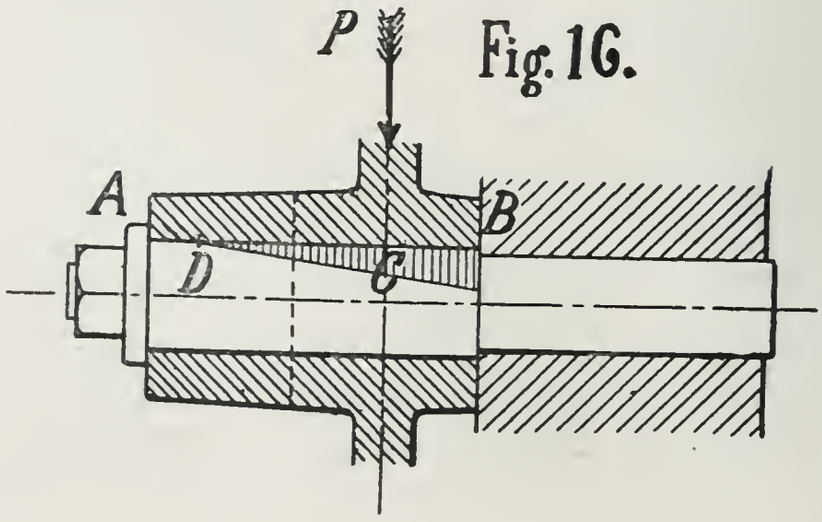


Fig. 16.

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pressure P can here not thrust the hub against the stud beyond the point D with $D\ C = 2\ B\ C$, as if we suppose $D\ C$ to be greater than $2\ B\ C$, we would have the center of resistance fall beyond P, which is impossible. The pressure at B will therefore be just twice what it would be if P acted in the middle of a hub of three times the length of the distance $B\ C$, and accordingly one and one-third as much as if acting in the middle of a hub only twice as long as $B\ C$.

Not only, therefore, is the maximum intensity of pressure reduced by adopting a central hub, no matter how short, but for a gear wheel the even greater advantage is obtained, of avoiding the increasingly tilted position on the stud.

Comparing a hub running loose on a shaft with one running on a fixed stud, a little reflection will make it evident that the latter case is a far superior arrangement to the former, contrary to the somewhat prevalent idea that there is but little difference between them.

In the former case the bore of the hub and the shaft will both retain their cylindrical form, the bore with increasing, the shaft with diminishing diameter, and thus the amount of contact surface between them will be very small and steadily on the decrease and make them liable to cut even under good lubrication.

In the case of a hub running on a stud, the bore of the hub alone will retain its cylindrical form, with increasing diameter, the stud wearing flat on the side receiving the pressure. The curvature of this flat will, however, always conform to the bore of the hub, and though its subtended angle is constantly becoming less, it will always, within permissible limits of wear, be so great that the effective bearing surface on the stud will fall but little below that of a fixed bearing with a running shaft.

Though it would be necessary, in an exhaustive consideration of this subject, to take account of certain things neglected in the previous examples, such as the influence of the obliquity of gear teeth on the resultant pressure on a shaft, the effect of the deflection of a shaft under constant and under variable loads, and of the reversal of the motion of a shaft, this would lead to complications which, without materially modifying the general rules laid down, would have carried us beyond the scope of the present discussion.

II.

INVESTIGATION OF THE STRENGTH OF GEAR TEETH.

By Wilfred Lewis, Active Member of the Club.

Read October 15, 1892.

To mechanical engineers, the strength of gear teeth is a question of constant recurrence, and although the problem to be solved is quite elementary in character, probably no other question could be raised upon which such a diversity of opinion exists, and in support of which such an array of rules and authorities might be quoted. In 1879, Mr. John H. Cooper, the author of a well-known work on "Belting," made an examination of the subject and found there were then in existence about forty-eight well-established rules for horse-power and working strength, sanctioned by some twenty-four authorities, and differing from each other in extreme cases about 500 per cent. Since then, a number of new rules have been added, but as no rules have been given which take account of the actual tooth forms in common use, and as no attempt has been made to include in any formula the working stress on the material so that the engineer may see at once upon what assumption a given result is based, I trust I may be pardoned for suggesting that a further investigation is necessary or desirable.

In summing up his examination, Mr. Cooper selected the following formula from an English rule published at Newcastle-under-Lyme in 1868, and, as an expression of good general averages, it may be considered passably correct.

$$X = 2{,}000\, p\, f \qquad (1)$$

in which

X = breaking load of tooth in pounds.
p = pitch of teeth in inches.
f = face of teeth in inches.

In conclusion he makes this pertinent observation: "It must be admitted that the shape of the tooth has something to do with its strength, and yet no allowance appears to have been made by the rules tabulated above for such distribution of metal, the

breaking strength being based upon the pitch or thickness of the teeth at the pitch line or circle, as if the thickness at the root of the tooth were the same in all cases as it is at the pitch line." Notwithstanding the fact that the necessity for considering the form of the tooth, as well as its pitch and face, was thus clearly set forth over thirteen years ago, I am not aware that any one else has taken the trouble to do it, and, as the results to be presented have been well tested by experience in the company with which I am connected, I believe they will be of interest and value to others.

In estimating the strength of teeth, the first question to be considered is the point or line at which the load may be applied to produce the greatest bending stress. In the rules referred to, the load is sometimes assumed to be applied at the pitch line, sometimes at the end of the tooth, and sometimes at one corner, but in good modern machinery, the agricultural type excepted, there is seldom any occasion to assume that the load is not fairly distributed across the teeth. Of course, it may be concentrated at one corner, as the result of careless alignment or defective design, in which the shafts are too light or improperly supported, and, for a rough class of work, allowance should certainly be made for this contingency, but, in all cases where a reasonable amount of care is exercised in fitting, a full bearing across the teeth will soon be attained in service. It must be admitted, however, that on account of the inevitable yielding of shafts and bearings, even of the stiffest construction, the distribution of pressure may not be uniform under variable loads, and that the assumption of uniform pressure across the teeth is not always realized in the best practice. To what extent it is realized I shall not attempt to estimate, but in general practice, where the width of the teeth is not more than two or three times the pitch, the departure can not be regarded as serious. The conclusion is therefore reached that in first-class machinery, for which the present investigation is intended, the load can be more properly taken as well distributed across the tooth than as concentrated at one corner. Having thus disposed of the first question the second is, at what part of the face should the load be assumed to be carried in estimating the strength of a tooth?

Evidently the load may be carried at any point within the arc of action, and it might be argued that when a tooth is loaded at its end, there are always two teeth in gear, and that the load should be divided between them. This is theoretically true of all teeth properly formed and spaced, but it must be admitted, that mechanical perfection in forming and spacing has not yet been reached, and that the slightest deviation in either respect is sufficient to concentrate the whole load at the end of a single tooth. In time this concentration may be relieved by wear, but it is not so easily corrected as unequal distribution across the teeth, and, as the present practice of cutting gears with a limited number of equidistant cutters makes it almost impossible to obtain teeth of proper shape, it is evident that the load cannot safely be assumed as concentrated at a maximum distance less than the extreme end of the tooth. In some cases, of course, the teeth will not be so severely tested, and the error in this assumption compensates in a measure for the error in the first assumption of equal distribution across the teeth. Having thus concluded that gear teeth may fairly be considered as cantilevers loaded at the end, the influence of their form upon their strength remains to be disposed of.

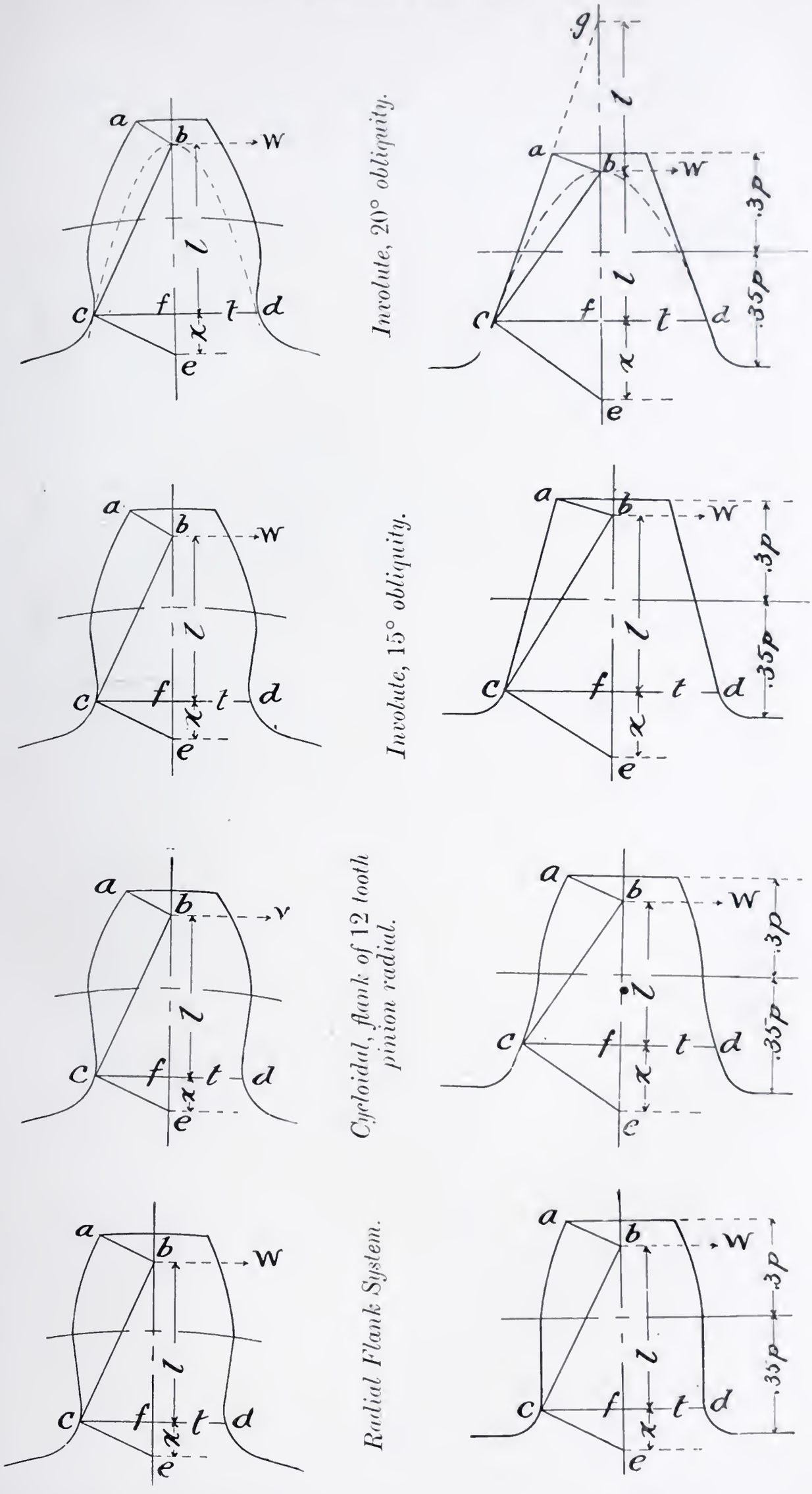
In interchangeable gearing, the cycloidal is probably the most common form in general use, but a strong reaction in favor of the involute system is now in progress, and I believe an involute tooth of $22\frac{1}{2}$ degrees obliquity will finally supplant all other forms. There are many good reasons why such a system should be generally adopted, but it is not my purpose at present to discuss the merits and defects of different sytems of interchangeable gearing, and I now propose to explain how the factors given in the table herewith were determined by graphical construction.

A number of figures were carefully drawn on a large scale, to represent the teeth cut by a complete set of equidistant cutters, making the fillets at the root as large as possible to clear an engaging rack. See Plate I.

The addendum was .3 p, and root .35 p, as shown in the illustrations, and the clearance .02 p.

When the load is applied at the end of a tooth and normal to its face in the direction $a\ b$, it may be resolved into two forces,

PLATE I.



12 *tooth pinions.*

Racks.

one tending to crush the tooth, and the other to break it across. The radial component which tends to crush the tooth directly, has but a slight effect upon its strength. In material which is stronger in compression than in tension, the transverse stress due to the other component, W, is partially counteracted on the tension side, and the teeth are stronger by reason of their obliquity of action, but in material which is weaker in compression the reverse is the case, and, in general, it may be said that the strength of teeth will not be affected more than 10 per cent. either way by the consideration of this radial component.

It should therefore be understood that for the sake of simplicity the factors given have been determined only with reference to the transverse stress induced by the force W, which may be regarded as the working load transmitted by the teeth. This load is applied at the point b, but it does not at once appear where the tooth is weakest, and, to determine that point, advantage is taken of the fact that any parabola in the axis $b\ e$ and tangent to $b\ W$ at the point b encloses a beam of uniform strength. Of all the parabolas that may thus be drawn, one will be tangent to the tooth form, and it is evident that the point of tangency will indicate the weakest section of the tooth. In the rack-tooth of 20 degrees obliquity, this is found at once by prolonging $c\ a$ to its intersection g with the center line $f\ b$, and laying off $b\ f = b\ g$; and, in other cases the weakest section $c\ d$ may be found tentatively to a nice degree of accuracy in two or three trials. Having found the weakest section, the strength at that point is also determined graphically by drawing $b\ c$ and erecting the perpendicular $c\ e$ to intersect the center line in e. $e\ f$ or x is then taken to measure the strength of the various forms of teeth.

To understand the reason for this construction and the actual relation which the distance x bears to the strength of the tooth, it will be observed that the bending moment $W\ l$ on the section $c\ d$ is resisted by the fibre stress s into one-sixth of the face f times the square of the thickness t, or, by the well-known formula for beams, we have

$$W\,l = \frac{s\,f\,t^2}{6}, \text{ or}$$

$$W = \frac{s\,f\,t^2}{6\,l} \qquad (1)$$

But by similar triangles

$$x = \frac{t^2}{4\,l} \tag{2}$$

and substituting this value in equation (1) we have

$$W = s\,f\,\frac{2\,x}{3} \tag{3}$$

or we may write

$$W = s\,p\,f\,\frac{2\,x}{3\,p} \tag{4}$$

$\frac{2\,x}{3\,p}$ or y is the factor determined by graphical construction and given in Table I for convenient reference. This is multiplied by the pitch face and fibre stress allowable in any case when the working load W is to be determined. What fibre stress is allowable under different circumstances and conditions can not be definitely settled at present, nor is it probable that any conclusions will be acceptable to engineers unless based upon carefully made experiments. In the article referred to, certain factors are given as applicable to certain speeds, and in the absence of any later or better light upon the subject, Table II has been constructed to embody in convenient form the values recommended. It cannot be doubted that slow speeds admit of higher working stresses than high speeds, but it may be questioned whether teeth running at 100 feet a minute are twice as strong as at 600 feet a minute, or four times as strong as the same teeth at 1,800 feet a minute. For teeth which are perfectly formed and spaced, it is difficult to see how there can be a greater difference in strength than the well-known difference occasioned by a live load or a dead load, or two to one in extreme cases. But, for teeth as they actually exist, a greater difference than two to one may easily be imagined from the noise sometimes produced in running, and it should be said, that this table is submitted for criticism rather than for general adoption. It is one which has given good results for a number of years in machine design, and its faults, such as they may be, are believed to be in the right direction from another point of view; for, when the durability of a train of gearing is considered, it would seem that all gears in the train should have the same pitch and face, be-

cause all transmit the same power, and are therefore subject to the same wear. But this argument is modified by the further consideration that equal wear does not mean equal life in a train of gearing, and a compromise between the considerations of life and strength must result in the adoption of values for different speeds, somewhat similar to those given in Table II.

TABLE I.

Number of Teeth.	Factor for Strength, y.		
	Involute 20° Obliquity.	Involute 15° and Cycloidal.	Radial Flanks.
12	.078	.067	.052
13	.083	.070	.053
14	.088	.072	.054
15	.092	.075	.055
16	.094	.077	.056
17	.096	.080	.057
18	.098	.083	.058
19	.100	.087	.059
20	.102	.090	.060
21	.104	.092	.061
23	.106	.094	.062
25	.108	.097	.063
27	.111	.100	.064
30	.114	.102	.065
34	.118	.104	.066
38	.122	.107	.067
43	.126	.110	.068
50	.130	.112	.069
60	.134	.114	.070
75	.138	.116	.071
100	.142	.118	.072
150	.146	.120	.073
300	.150	.122	.074
Rack.	.154	.124	.075

TABLE II.

SAFE WORKING STRESS, **s**, FOR DIFFERENT SPEEDS.

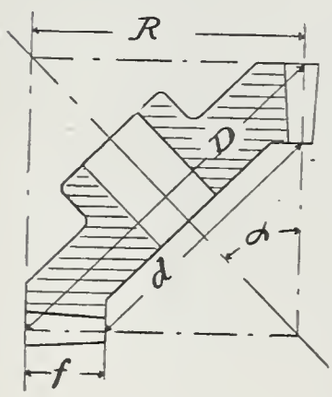
Speed of Teeth in Ft. per Minute.	100 or less.	200	300	600	900	1200	1800	2400
Cast Iron	8,000	6,000	4,800	4,000	3,000	2,400	2,000	1,700
Steel	20,000	15,000	12,000	10,000	7,500	6,000	5,000	4,300

To illustrate the use of Tables I and II, let it be required to find the working strength of a 12-toothed pinion of 1 inch pitch, $2\frac{1}{2}$ inch face, driving a wheel of 60 teeth at 100 feet or less per minute, and let the teeth be of the 20-degree involute form. In the formula $W = s\,p\,f\,y$, we have for a cast-iron pinion,

$$s = 8{,}000,\ pf = 2.5,\ \text{and}\ y = .078,$$

and multiplying these values together we have $W = 1{,}560$ pounds. For the wheel we have $y = .134$, and $W = 2{,}680$ pounds.

The cast-iron pinion is, therefore, the measure of strength, but if a steel pinion be substituted, we have $s = 20{,}000$ and $W = 3{,}900$ pounds, in which combination the wheel is the weaker, and it therefore becomes the measure of strength. In teeth of the involute and cycloidal forms, there is a marked difference between racks and pinions in working strength, while in radial flanked teeth, which are used more especially on bevel gears, the difference is not so pronounced. These teeth are to be found in the great majority of all cut bevels, because they can be more cheaply produced on milling machines and gear cutters, but the 15-degree involute bevel-tooth, as made by the Bilgram process, is superior in accuracy of form and finish, and is often preferred for patterns and fine machinery. There are, therefore, two well-defined forms of bevel gears to be considered; and to bring the strength of bevel gearing within the scope of the present investigation, it will be necessary to understand how the variation in their pitch and radius of action is allowed for, and without going into a demonstration of the formula, its simple statement will probably be sufficient.



Referring to the figure,

D = large diameter of bevel.
d = small diameter of bevel.
p = pitch at large diameter.
n = actual number of teeth.
N = formative number of teeth.
n = secant a, or the number corresponding to radius R.

f = face of bevel.

y = factor depending upon shape of teeth and formative number N.

W = working load on teeth referred to in diagram D.

Then it can be shown that

$$W = spfy \frac{D^3 - d^3}{3\,D^2\,(D - d)} \qquad (5)$$

To illustrate the use of this formula, let it be required to find the working strength of a pair of cast-iron mitre gears of 50 teeth, 2-inch pitch, 5-inch face, at 120 revolutions per minute.

In this case, $a = 45°$, $D = 31.8$, $d = 24.8$, and secant $a = 1.4$, $N = 50 \times 1.4 = 70$, for which $y = .071$. The speed of the teeth is 1,000 feet per minute, for which, by interpolation in the table, $s = 2{,}800$, and the formula becomes by substituting these values,

$$W = 2{,}800 \times 2 \times 5 \times .071 \times \frac{31.8^3 - 24.8^3}{3 \times 31.8^2\,(31.8 - 24.8)}$$
$$= 1{,}988 \times .795 = 1{,}580 \text{ lbs.}$$

This result is attained by some labor which is practically unnecessary, because d should never be made less than $\frac{2}{3}\,D$, and when this rule is observed, the approximate formula,

$$W = spfy \frac{d}{D} \qquad (6)$$

gives almost identical results. The reason for fixing a limit to the ratio $\frac{d}{D}$ is found in the fact that a further increase in face adds very slowly to the strength and increases very rapidly the difficulty of properly distributing the pressure transmitted. Where long-faced bevels are used, the teeth near the shaft are generally broken by improper fitting, or, when properly fitted, by the spring of the shaft or the yielding of its bearings, and, as the limit imposed gives about 70 per cent. of the strength attainable, by extending the face to the center, it is thought to be as liberal as experience can justify.

In presenting certain forms and proportions for teeth, on which Table I is founded, I am aware that other forms and proportions are in common use, which have some claims to recognition, but my chief object at present is to show that the strength of gearing can be reduced to a rational basis of comparison on which all authorities may ultimately unite.

III.

THE WATER SUPPLY OF PHILADELPHIA.

By Henry Leffmann, M.D., Active Member of the Club.

Read November 5, 1892.

A study of the literature of hygiene, especially its periodical literature, will show very clearly that while, perhaps, in some fields of research, laboratory methods are most important, the great probems of sanitation are now so largely engineering problems, that no sanitarian can afford to neglect this feature of the question. While on a small scale, in isolated residences, for instance, the simpler principles of physics and chemistry may afford a solution of a given sanitary problem, the methods of dealing with the enormous aggregations of population so characteristic of the present day, and which are in this country, at least, the products of such rapid growth that it is almost impossible to adapt a natural condition, *pari passu*, to the development, require the accurate knowledge of the educated engineer.

In considering the subject of the water supply of Philadelphia, I must remark that it seems to me to be one in which chemical (in which term I will in this paper always include bacteriological) examinations are of but limited value. If we assume, as we certainly may, for the purpose of this paper, that the supply for the city will come from some body of surface water, river or lake, we will find that there is no department of water analysis in which there is less opportunity for standards of comparison than with regard to surface waters. It is difficult to fix upon a limit of impurity with reference to those ingredients which are either regarded as dangerous or as indicative of past pollution. With the waters of wells or springs, or artesian waters, we have tolerably precise standards and principles, and, knowing the average character of a subsoil water of a district, we can with confidence approve or condemn a given well or spring. River waters, however, are subject to much variation. They may at times be perfectly clear, and the dissolved matters, both mineral and organic, be found decidedly below the limits assigned as standards

of impurity. A storm may alter the condition within a few hours and the water become so turbid as to be repulsive. Intermediate conditions of turbidity, often so slight as to scarcely attract attention, are frequently associated with the presence of dangerous materials. It must not be supposed, however, that in discussing the question of a water supply of a large city, the chemist can lend no aid. All such supplies involve the question of supervision and treatment, and, in determining the daily condition of samples, in detecting deterioration before it becomes evident to the senses, and in comparison of the effects of storage, aëration, filtration, etc., chemical analysis is of great service. With the knowledge that has been acquired within the last ten years concerning the propagation of the diseases arising from polluted water, we find that the inspection of a watershed may serve more satisfactorily to detect possible dangers, than even an elaborate study of the dissolved and suspended matters at the point of intake. The question of self-purification of water has been discussed at some length in sanitary literature. The conflicting utterances of some of the more eminent authorities may depend, partly, upon personal feeling: but it must be admitted that the power of any stream to destroy in its course dangerous pollution, will be so largely modified by conditions of weather and temperature that nothing but an almost continuous examination of samples could keep us informed as to the presence or absence of specific germs.

At this point, while avoiding too much laboratory science, I deem it proper to say that great caution must be exercised in accepting the results of the bacteriological examination of water samples. Mere microbe counting—*i. e.*, the determination of the actual number of living organisms present in a given volume of water—can be carried out with considerable accuracy, and when the object is to attain comparative results, as in studying a sample before and after filtration, before and after prolonged storage, or in determining the effect of sterilizing methods, the results are trustworthy even in not very expert hands. When, however, it becomes necessary to recognize and identify specific forms, especially such as are believed to cause typhoid fever, associated with many other similar organisms, the problem is

one of great difficulty, requiring special laboratory facilities and much biological knowledge. I am inclined, therefore, to doubt a certain proportion of the statements in which the detection of some specific microbe is noted, and I am not aware that competent bacteriologists have ever claimed to be able to recognize the germ of typhoid fever by microscopic examination alone. Certainly the authorities in this field are unanimous in saying that only by careful culture by special methods can we differentiate this organism. I make this assertion because I have seen reports of water analyses in which reference is apparently made to the detection of typhoid germs by microscopic examination. I have also seen photographs purporting to be taken directly from specimens, but I am compelled to say that I do not regard such methods as acceptable.

The improvement of the water supply in Philadelphia has been a subject of discussion in the newspapers and in department reports for a long period. It seems that no sooner does this question arise for discussion, than it is complicated by some proposition which is either justly or unjustly suspected of being of pecuniary benefit to some person or persons. It would be ungracious to impute improper motives too freely, but I think that it cannot be denied that, within the past twenty years, several propositions entirely selfish in motive and disadvantageous to the Philadelphia public, have been put forward and an effort made to secure a hasty acceptance under an alarm brought about by mortality statistics and chemical analyses. The plans proposed for the improvement in the Philadelphia supply usually involve the selection of a new source, and contemplate the entire abandonment of the Schuylkill, it being asserted, or assumed, that the Schuylkill water is absolutely unsuitable both as to quality and quantity.

The pollution of the Schuylkill cannot be doubted, although analytical examinations made upon the perfectly clear water often give favorable results. One of the most severe of the critics of the Schuylkill has admitted in his report that the water is at times unexceptionable in quality, yet a journey along the banks of the river will demonstrate beyond all question the many sources of contamination and danger that must constantly im-

pend from a water supply receiving the discharges from so many populated points. The pollution is especially notable when the river is turbid. In the year 1888, from September 17th until October 11th, I made, in association with Dr. William Beam, a test, every week-day, of the water as supplied at my laboratory, No. 715 Walnut Street, and I append here a table showing the condition—total solids, the so-called albuminoid ammonia, and free ammonia—expressed in terms of the nitrogen they contained, which will serve to show the great variation in suspended and dissolved matters within this limited period. Undoubtedly, analagous results would be obtained by a consecutive study of the water at the present time, though, so far as the particular locality is concerned, the extension of reservoir capacity seems to have enabled a clear water to be supplied more continuously.

1888.	CONDITION.	TOTAL SOLIDS.	NITROGEN BY $K\,M_n\,O_4$	NITROGEN a $N\,H_4$
Sept. 17	Turbid.	160	.06	.048
" 18	Muddy.	160	09	.020
" 19	Turbid.	140	.108	.004
" 20	"	150	.124	None
" 21	Less turbid.	150	.132	None
" 22	Very muddy.	180	.180	None
" 24	Turbid.	140	.100	None
" 25	Slightly turbid.	130	.092	None
" 26	" "	120	.068	.01
" 27	Very slightly turbid.	110	.056	None
" 28	" " "	105	.052	None
" 29	Nearly clear.	125	.052	.008
Oct. 1	" "	140	.052	.012
" 2	" "	125	.044	None
" 3	" "	120	.080	.016
" 4	Clear.	120	.084	.008
" 5	"	120	.092	.012
" 6	"	120	.060	.012
" 8	Turbid.	150	.108	.008
" 9	Slightly turbid.	130	.088	.008
" 10	Almost clear.	125	.056	.010
" 11	Clear.	115	.044	.010

Two tests were made lately with following results:

1892.	CONDITION.	TOTAL SOLIDS.	NITROGEN BY $K\,M_n\,O_4$	NITROGEN a $N\,H_4$
Oct. 28	Clear.		Trace	None
Nov. 4	Slightly turbid.		0.08	None

The influence of turbidity is here indicated.

The typhoid death-rate in this city has been a subject of much sanitary interest for a considerable time. This cosmopolitan disease, seeming to accompany humanity under almost every condition, occurring in crowded cities, attacking crews and passengers in the open sea, and afflicting isolated residences apparently in perfect sanitary condition, may, when the significance of large numbers of cases is concerned, be taken as a fair index of the sanitary condition of the community. We may, however, overrate the value of such statistics. If we accept the view that the fever is caused by a specific germ, absolutely distinct, we must, of course, assume further that it can never originate from particular coincidences, but must be transmitted from some previous case. While it is not appropriate to discuss here a question so medical as the causation of typhoid fever, it is well to note that a prominent American authority, Dr. Vaughan of Ann Arbor, inclines, as the result of much personal investigation, to the view that the so-called typhoid bacillus is but a modified form of some of the harmless water bacteria, a position which, if even rendered probable, must disturb seriously our notions as to the relations of this disease to general sanitation. In Philadelphia there has existed for some years a comparatively high typhoid death-rate, exceeding that of most of the large cities of the world. The existence of the disease has unhesitatingly been ascribed to the Schuylkill River, and while it may be safely agreed that a marked improvement in this respect would follow the introduction of an absolutely pure water, yet the fact is that a considerable percentage of the excess over the death-rate of other cities occurred in a district of the city not entirely supplied by Schuylkill water. Some years ago I made a study as to the location of every death occurring in the city during a year, collecting information in regard to most of the cases by direct communication with the physician reporting the deaths. These results were presented in a paper read before the Philadelphia County Medical Society, and indicated that in the district of the city north of Poplar Street and east of Sixth Street, embracing about one-fifth the entire population of the built-up portion of the city, there occurred about one-half of the total number of deaths

from typhoid fever. The unsuitability of the Delaware supply was well shown by this fact, and has been further demonstrated by the marked lowering of the death-rate in this section since the supply from Otis Street was abandoned. I append here some figures showing the typhoid death-rate in certain sections of the city for a period of some years before the abandonment of the Kensington supply and extending up to the latest available statistics.

Deaths from typhoid fever in the district east of Sixth Street and north of Poplar, in the city of Philadelphia, comprising the Sixteenth, Seventeenth, Eighteenth, Nineteenth and Thirty-first Wards, from 1884 to 1891, both inclusive, together with the deaths from the same disease over the entire city and in the Fifteenth Ward:

	ENTIRE CITY.	FIFTEENTH WARD.	KENSINGTON DISTRICT.
1884	662	25	160
1885	610	19	161
1886	618	19	153
1887	621	20	181
1888	785	31	211
1889	736	42	126
1890	666	45	53
1891	683	52	57

The figures for the entire city and for the Fifteenth Ward, which latter is selected because it is a large ward, mostly in good sanitary state, show that the marked decrease in the Kensington district is not due to any general abatement of the disease. The increase in the Fifteenth Ward is doubtless due in great part to the increase in population.

Table showing total deaths per month from typhoid fever in Philadelphia in 1889, with pumpage at Kensington Water Works in millions of gallons, and deaths from the fever in Kensington district (Sixteenth, Seventeenth, Eighteenth, Nineteenth and Thirty-first Wards):

MONTH.	TOTAL DEATHS.	MILLIONS PUMPED.	DEATHS IN KENSINGTON DISTRICT.
January	62	0	6
February	55	0	3
March	61	10	3
April	41	173	5
May	64	149	19
June	50	131	21
July	68	196	19
August	53	171	15
September	70	101	9
October	63	49	12
November	33	0	6
December	66	0	6

It must be understood that in speaking of the Delaware supply I refer to that taken at the foot of Otis Street, and not to that pumped from Lardner's Point, which has generally been found satisfactory.

All will admit, I think, that whatever view be held as to the relation of water supply to general health, or as to the special question of the suitability of the Schuylkill or Delaware rivers as sources of supply to this city, the improvement should be of such a character as to be substantial and permanent. In view of the difficulty with which large communities are aroused to liberal assistance in public works, it will be better to introduce such changes as will enable the city to furnish, from the present sources, an abundant supply of water of as high degree of purity as is attainable by natural and artificial means. In short, I have to suggest, as the principal point in this paper, the temporary setting aside of the discussion and investigation of new sources of supply and the limitation of immediate action to the construction of storage and purification facilities. Much as we may suspect the Schuylkill water, it has been noted above that it is sometimes of fair quality. Evils which have resulted from its use in this city have certainly been due in part to the direct pumpage of it from the river to the houses without any opportunity for subsidence. It has been frequently delivered in a condition actually repulsive.

By the employment of small amounts of precipitants, or by boiling, even polluted water may be rendered safe; but few citizens will resort to such methods, and a public water department

is a useless burden on the community if it does not furnish a water in condition to be employed freely without treatment. In addition to the complaints as to the quality of the water supply to the various parts of the city, there is much complaint in some localities as to the deficient amount. I consider that a very great step toward relief both as to the quality and quantity of the supply would be secured upon the introduction of abundant storage capacities. This is no new observation. It has been frequently noted in connection with the suggestion for the improvement of our condition, but it needs to be pointed out, I think, that such storage capacity would be beneficial from several points of view.

In the first place, if the storage capacity were of such a character as to give us, when charged to its fullest capacity, twenty-five or thirty days' supply under moderate demands, it would enable the pumping to be discontinued at times when the river was in an unsatisfactory condition. In this way a much smaller quantity of subsiding material would be introduced into the basins and danger from drought would be diminished.

Secondly. There is a good deal of experimental evidence to show that a material improvement in the wholesomeness of water results from its storage in suitable reservoirs, this improvement being the result partly of subsidence, but largely of the changes that take place in the organic life present. Even noxious organisms may be destroyed by such methods.

Thirdly. An advantage of these reservoirs would be that under any method which may hereafter be adopted, it would be advisable and even necessary for the city to be able to maintain within its bounds a supply of water for a considerable number of days. Even should we go to the Upper Delaware or Lake Erie for our water, it seems to me it would be a grave engineering mistake to depend from day to day upon the supply through the conduit that might be constructed. Accidents to the aqueduct, the presence of a hostile force, or even of an excited mob in the immediate territory, might serve to deprive the city of this water. It would be far better able to meet such emergencies which may at any time occur, if it had within its bounds a total reservoir capacity of, say three thousand million gallons. Under great stress

and careful supervision such an amount may be made to last double the time that it would otherwise, and thus afford opportunity for the construction of supplemental methods of supply. It is objected occasionally that the storage of water in large masses for a considerable time results in the development of vegetable growths which give a disagreeable odor and taste. This condition does not appear to be associated with any real sanitary defect, nor to occur appreciably when the water is stored in a fairly pure condition and the basins kept free from mud and decomposable organic matter. Dr. Thomas M. Drown, in an article upon the effect of aëration on water (Report, State Board of Health, Mass., 1891), states that "while in the case of Jamaica Pond, Boston, Mass., the water became foul from stagnation, yet in basin No. 4 of the Boston Water Works, which was carefully prepared for the reception of the water by the removal of all soil and vegetable matter, and is supplied with a brown swampy water from a water-shed almost entirely free from pollution, the water is good at a depth of forty feet, because the water contains very little organic matter with a tendency to decompose." Even with waters not of the best quality, as far as organic impurities are concerned, a material improvement may be secured by agitation of the water, such as is brought about by continuous aëration, and it may be worth noting, in passing, that from the numerous experiments recorded by Dr. Drown in the same pamphlet, it appears that no appreciable influence on the amount of nitrogenous organic matter is produced by even long-continued aëration under strong pressure. Samples of water, both of good and bad quality, have been treated for periods varying from forty-two hours to thirty days without material diminution in the proportion of organic matter, as shown by the albuminoid ammonia yielded, or by the quantity of oxygen required for complete oxidation. Nor was there a material increase in the proportion of nitrates, or diminution in the amount of nitrites. The view, therefore, that aëration of water will render it more wholesome, seems to have no foundation. In fact, since we now know very clearly that the transformation of the organic matters of water into nitrates and nitrites takes place under the influence of living organisms, we are not surprised to learn that

these organisms cannot be forced by an additional supply of oxygen to do more oxidizing work than they would do under normal conditions. Dr. Drown inclines to the view that the prevention of the growth of algæ, which is noted as one of the beneficial effects of aëration of water, is due to the agitation, and not to the additional supply of oxygen. Further, it must be noted that the removal of odors from water can be accomplished by a current of carbonic oxide as well as by a current of air. This is dependent upon the well-known physical law that constant exposure of a fluid to the atmosphere of any particular gas will withdraw from solution in it another gas.

In addition to the construction of large storage reservoirs, the introduction of some purifying system would be appropriate. There is no reason to doubt that a material benefit can be brought about by the employment of methods now available. Of these the simplest is probably sand filtration, which method is in operation on an extensive scale in many places. As a summary of the results that have been obtained on a practical scale, I present the following notes on the efficiency of sand filtration in use at the Zürich Public Water Works (J. S. C. I., December, 1889). In this system both covered and uncovered filters are employed. The former require cleaning once in seven days, the latter once in forty-eight days. Under normal conditions the filter is free from microbes, although a few are taken up again in the latter stages of filtration. After cleaning the filter, the water which passes through is not in a normal condition, an efficient layer or scum not having had time to collect on the sand, though the chemical purity of the water is satisfactory. When the filters have not been used for some time the water which first passes through them contains more bacteria than usual, owing to their rapid multiplication in stagnant water, but its chemical purity is not materially different from the normal filtered water. In the absence of facilities for the establishment of sand filters of the class above noted, several forms of pressure filters employing a coagulant, such as alum, are available. With proper supervision as to the quantity of coagulant used, and especially with abundant storage capacity which will enable the filtering system to be worked as a mere accessory to the supply, it seems to be pos-

sible to furnish the citizens of Philadelphia at all times with an abundant amount of perfectly clear water, suitable for all purposes, even when taken from the Schuylkill or Delaware within the city limits. Other filtering systems depending upon less understood chemical principles have been shown to be efficient, and several of these more modern methods have been demonstrated at meetings of this Club. Some attention has lately been drawn to the employment of electrical currents through iron electrodes immersed in the water, and experiments show that a material improvement results in this manner, as far as the dissolved organic matter is concerned.

One of the most notable defects in the Philadelphia water supply is the want of systematic methods for the prevention of waste. Not only has the Department given insufficient attention—at least so far as practical results are concerned—toward securing economy in the employment of water, but there is abroad in the community a foolish spirit that restriction in this respect is disadvantageous. The *per capita* consumption of water in Philadelphia is very high, and from conversation with engineers familiar with the more economical systems of European cities, I believe that two-thirds of the present consumption could be made amply sufficient for the purpose. Among the steps that should be taken to secure this economy would be the introduction of measurement systems at all points, where either the water has a purely trade value (that is where it is not merely conducive to personal comfort, cleanliness or bodily needs), and also at all points at which water is used so irregularly that the average employment cannot be accurately estimated. Hydraulic engineers are, as I believe, not favorable to the introduction of water meters in private houses. A sufficiently close approximation to the daily use can be made in these cases, according to the size of the house, the neighborhood, and the appliances for the use of water, so that the expense of measurement apparatus may be avoided; but large establishments, even hotels, and, certainly, manufacturing places, should pay for the water in proportion as they use it. In estimating the water rate, even in private houses, the decisions should be based upon the type of apparatus in which the water is used. Certain forms of house-

hold appliances are apt to be very wasteful, and the use of these should be discouraged by the imposition of a higher rate wherever they are employed. The hopper water-closet, for instance, is frequently allowed to run continuously and cause much waste. Flushing systems should, therefore, be preferred. I have seen in sucessful operation at several points, a system of closets depending entirely on subjecting the fæcal matters to a continuous air-current, by which they became very soon sufficiently dry to be burned. This method does not involve the use of water, and its general use would result in much saving.

A reasonable amount of attention should be given to the condition of the supply in all establishments, that is, in regard to leakage, whether from pipes or from defective fittings. Much water, doubtless, runs to waste in Philadelphia in consequence of overflowing of storage tanks on the upper floors of the large residences. The overflowing pipes of these tanks, which by the careless or ignorant plumber are usually connected to the soil-pipes or ventilating shaft, and by the more careful plumber to the rainwater conduit, either directly or over a portion of the roof, may be almost continuously discharging without attracting the attention of the householder or the inspectors. The automatic control will, of course, when it works properly, prevent this waste; but in the loft of a building it is but rarely that such an apparatus will be kept under supervision, and when, as is always the case, the overflow pipe is provided as a protection against accident, it is simply human nature of the householder to rely exclusively upon that. In at least one of the European cities, the ingenious expedient is adopted of so arranging the overflow pipe that it empties directly from the eaves on to the pavement, thus giving public notice of any failure of the automatic control.

Probably there is no more objectionable form of waste than that which arises from the wash-paves. I believe the custom of deluging the sidewalks with water is carried to a greater extent in this city than in any other. Certainly it would be difficult to find a city in which the practice is more extensive. Much of this is unnecessary. Sufficient cleanliness could be obtained by sweeping the pavement, especially if good methods of paving are adopted. One has only to watch the method pursued to see

that the entire arrangement promotes waste without securing any particular sanitary or sentimental advantage. The curved discharge-pipe permits the water, generally at full head, to run into a bucket; the current is kept on continuously, and, though I have never made any measurement of the amount of water employed in the washing of an ordinary pavement, I feel satisfied that several times the amount is used that would be needed even when the pavement required washing. The simplest method, it seems to me, outside of actual prohibition, would be the imposition of a very heavy annual rental for the attachment of such pipes.

One source of waste in the supply of large cities is so purely a matter of hydraulic engineering, that I do not feel that I could more than indicate it, with the hope that some facts will be brought out in the discussion. It also belongs to most city supplies, that is, the waste from leakage from originally imperfect joints, settling of pipes, corrosion, etc. No doubt, that in a total area, in a large city like Philadelphia, this source of waste must be a considerable item.

Waste in a city water supply involves more than the objectionable feature of extra cost for furnishing the water. It involves greater wear and tear on all forms of apparatus, and by adding to the dilution of the sewage from the district, increases the expense and trouble of dealing with it. There is no more important problem in sanitary engineering than this question of sewage disposal. One step towards a practical solution of the problem in such a city as this will be, by diminishing the waste of water, to diminish the volume of offensive liquid produced. Did the limits of this paper permit, I should like to discuss at this point some system of disposal of offensive matters which avoid the employment of water and yet secure the prompt and safe treatment of the material. A wise administration of the water department will seek, by legislation and judicious levying of fixed charges, to encourage all methods which will secure economy without causing inconvenience or sacrificing safety.

Concerning this matter of waste, I take the following data from the Annual Report of the Bureau of Water for 1891, pages 95–8:

Square from Broad to Thirteenth, Walnut to Spruce Streets,

containing no manufacturing establishments, 104 dwellings, 12 stables, 15 other establishments, with a total population of 794. There are 96 hydrants, 71 wash-paves, 384 kitchen spigots, 244 bath tubs, 255 wash-stands, 181 closets, of which 134 use flushing tanks, 18 urinals. The total water rent is $2,335.55. The consumption of water is 113 gallons *per capita.* The annual charge for a urinal is $2.00; the minimum water necessary for proper washing would cost by meter $33.58 per year; the amount used if the urinal runs at full capacity would cost $179.85. The total water consumption of the district was 89,000 gallons per 24 hours, 43,000 of which, or nearly half, was consumed by the urinals. As the report remarks: The only check that can be put upon them is a meter, which will either make payment for the water used or compel the shutting off of the water when the use of the appliance is not required.

Another experiment in the Twenty-eighth Ward showed that a manufacturing establishment was using $\frac{1}{17}$ of the water pumped to the district. This establishment was paying $1,792.00 water rent, while by meter the amount payable would be $17,520.00

The third experiment was made in a manufacturing district of the Thirty-first Ward, containing 200 dwellings, 13 manufacturing establishments, 7 dye-houses, a total resident population of 849, and a transient population of workmen of 1,733. The consumption equalled 1,522 gallons *per capita* of the resident population.

An essential point in the construction of reservoirs is almost entirely overlooked in American cities: this is the necessity for complete protection of their contents from accidental or intentional pollution. I believe that the common practice of making such reservoirs places of public resort, is an error. They should be kept entirely under official observation and the public should be excluded. No inconvenience would result from this plan, and the protection of the water supply would be promoted.

If a new source of supply is to be obtained for Philadelphia, its selection should be made with the greatest care. Unless a complete control of the whole area concerned in the furnishing of the water is secured by the municipality, the change of source

would be only of temporary advantage. If an expensive system is to be constructed, and in a few years the city is to be obliged to protect itself from some newly developed source of pollution by the slow and uncertain method of legal procedure, or the highly expensive remedy of purchase, under condemnation or bargaining, of the territory of the offending settlers, we will find that we have accomplished but little in the way of improvement.

From time to time the suggestion occurs to hydraulic engineers as to whether a double supply is feasible. In Philadelphia it might be possible to secure the use of the Delaware water, which is abundant and sometimes even better adapted for manufacturing use than Schuylkill, for supply over the same territory as that receiving better water. There are, however, grave difficulties in such an engineering enterprise. Not only do we have the question of the expense of installation, but if the water should be furnished more cheaply or even more abundantly, the temptation to use it for all purposes might lead to serious sanitary results. Some of this danger might be avoided by excluding residences from the benefits of the supply, but even if it were limited to large manufacturing establishments the liability of the workmen to use the water would be great, and epidemic dysentery or more serious results would certainly occur.

It is beyond the scope of this paper to discuss at length the relative advantages of public and private ownership of waterworks, yet I would like to express my opinion that under no circumstances should the citizens of Philadelphia part with any portion of the control of the water supply and distribution. However strongly we may feel on the question of the difficulty of securing economical, honest and judicious management of public works, the control of the water supply is certainly one thing that should be retained by the municipality. Water is an absolute necessity. When its quality and quantity are subject to the greed of a private corporation, the oppression may be most serious, because the citizen has practically no alternative. Substitutes may be found for many other of the requirements of civilized life. If a private company possessing the monopoly of supplying gas or electricity to a city neglects or refuses to furnish

a suitable service at reasonable cost, the citizen may at least find some substitute for the light. If a street car company fails to maintain a sufficient number of cars to carry the passengers, private conveyances are at least available, but if impure or insufficient water is furnished, the burden is most distressing. It is to be hoped, therefore, that, whatever may be done in developing the water supply of Philadelphia, a complete control of it will be maintained by the city authorities.

DISCUSSION.

Mr. W. W. Thayer: The reservoir capacity of the city of Philadelphia, at this date, is 869,288,814 gallons, and the total pumping capacity of the engines at the various pumping stations is 184,540,000 gallons per day. It would seem, therefore, to a casual observer, that if the reservoirs of the city were empty, it would take about four days to refill them, supposing all outflow gates to be closed.

But this is not the case, as the capacity is so unevenly divided that it would take much longer to fill some reservoirs than others. In the case of the East Park reservoir, with its capacity of 673,874,614 gallons and the daily pumping capacity of the Spring Garden, Belmont and Fairmount stations (147,-290,000 gallons), were it possible to direct the whole pumping energy of these three stations on this reservoir, it would take four and one-half days to fill it, while the other reservoirs also dependent on these pumps were standing dry and idle. It would seem, therefore, that the pumps are insufficient. This is true, and the Director of Public Works, in the excellent report made by him this year, states that he has asked Councils for a 20,000,000 gallon engine for Spring Garden, a 10,000,000 gallon engine for Belmont, a 10,000,000 gallon engine for Roxborough, and a 15,000,000 gallon engine for Frankford. This will increase the pumping capacity 55,000,000 gallons.

I have mentioned these above figures in order to bring before you the existing condition of the water supply of Philadelphia. The storage reservoirs can be too large as easily as they can be too small. The writer of the article: "The Water Supply of

Philadelphia," proposes to more than triple the present storage capacity.

The cost of construction and maintenance, of course, increases in proportion with the magnitude of the work. The present supply, with the reservoir which is now being built, with its capacity of nearly 150,000,000 gallons, will aggregate a total storage capacity of about 1,000,000,000 gallons. Let us add to this, one-quarter of this whole capacity for future growth of the city, and one-quarter again for dead water or a reserve reservoir, in case of drought, and we will have a desired total capacity of 1,500,000,000 gallons storage capacity, or one-half the amount that the writer advocates. The storage of such a capacity, namely, 1,500,000,000 gallons, would necessitate the construction of reservoirs necessary to store, in addition to the present supply, 500,000,000 gallons, or thirteen reservoirs 500 feet square and 20 feet deep.

An estimate for the cost of such a work is hard to imagine, but in my opinion the construction of storage reservoirs which would accommodate 2,000,000,000 of gallons, or four times the above amount, is at this time out of the question.

Regarding the FILTRATION SYSTEM; can a system be found which will filter water properly and yet in sufficient quantities to furnish a supply adequate to meet the demands of a city of over 1,000,000 inhabitants? About sixty gallons is the appropriate allowance *per capita*, as found by experience, though some cities waste half as much more; as Philadelphia is classed among the wasteful cities, and supposing each inhabitant used, with waste, ninety gallons, and suppose the water population to be 1,000,000, then, naturally, 90,000,000 gallons are required daily to supply the city of Philadelphia.

Let us take the case of the largest of the city reservoirs, the East Park reservoir, which supplies the wants of 335,000 people, and suppose the consumption of water by these people is only ninety gallons *per capita* per day; we then need a filtering plant here which will filter at the least ($90 \times 335{,}000 = 30{,}150{,}000$) thirty million one hundred and fifty thousand gallons per day, or a solid column of water 15.5 feet long by 1 foot thick, dropping three feet in one second, for the entire day. I claim that

such filtration is a little better than naught and would have no effect whatever upon the destruction of the germs of zymotic diseases, such as diphtheria, scarlet fever, typhoid, Asiatic cholera and the like. It would be wiser to call it sifting rather than filtering. The golden rule for filters is, "What is lost in time, is gained in purity;" and purity can only be obtained by a slow percolation through a series of closely packed strata.

The question of the feasibility of a double supply is a new subject to me, and a most excellent suggestion for adoption in new and growing cities; but in a city like Philadelphia, the cost of instituting such a system would be almost equal to the fitting up of an entirely new system, inasmuch as a new system of supply pipes must necessarily be laid, new connections with houses, exterior and interior, made, and all streets repaved over the trenches. The whole cost of the enterprise would necessarily fall on the city corporation, its adoption being necessarily a compulsory step.

Unless I am mistaken by the wording of the abstract, the author is unwilling to consider the question of a new source of supply.

This is, in my opinion, the ultimate goal for the water supply question. By the construction of another reservoir smaller than the present East Park reservoir, with a capacity of 500,000,000 gallons, we would have the required storage capacity of 1,500,000,000 gallons of water.

The rivers of the eastern part of the State available for the supply of the city, are the upper Delaware, the Lehigh, the upper Schuylkill, and the north branch of the Susquehanna.

The upper Delaware is available at the Delaware Water Gap. The river, here, has the impurities disgorged from Stroudsburg (via Broadhead Creek), Milford and Honesdale (via the Lakawaxen). This is a beautiful water now, but cannot be counted on should these three towns grow into cities of the first class. The nearest available tapping place is distant seventy-two miles as the crow flies.

The upper Schuylkill, besides draining Pottsville and many smaller towns, is strictly a mine water, with the chemical impurities attendant thereto, and the nearest point of connection

should be above Reading, about fifty-five miles from this city in a straight line.

The north branch of the Susquehanna drains Danville, Bloomsburg, Wilkesbarre, Scranton, Tunkhannock, Towanda, to say nothing of Oswego, Binghamton, and other large New York towns. The nearest advantageous tap to this river is a point above Scranton, about one hundred and ten miles from Philadelphia.

The Lehigh River, if tapped above Allentown, would, in my opinion, furnish us with the purest water, at the least expense of construction and maintenance.

The only large town on this river, above Allentown, is Mauch Chunk, which would be twenty-four miles up stream from the proposed tapping place.

This aqueduct, which should be open for aëration as much as possible, would be about fifty-five miles long, with perhaps five pumping stations, various tunnels and arched ways.

The present *Perkiomen Creek* should be used for a distance of twenty-one miles as the natural channel. We would, therefore, have a connection to build between the Lehigh River and the Perkiomen Creek, about seventeen miles in length, and a connection between the Perkiomen Creek and the Philadelphia reservoirs, about twenty-four miles long. With this forty-one miles of aqueduct the city would be supplied with water from streams of two of the purest water-courses in the eastern part of the State.

Mr. Wilfred Lewis: Will Dr. Leffmann tell us what system of filtration he has in mind, and whether he knows anything about the Devonshire method?

Dr. Leffmann: I had no particular system in mind, but I have looked into the one you refer to, and consider purification by iron very good. It acts more readily in some waters than in others, but tests have shown that it destroys the microbes in all kinds.

Mr. John E. Codman: I regret that I had not time to prepare a formal discussion on this subject, but would say that, as regards the quantity of water supplied by the Schuylkill, a storage capacity of 100,000 gallons per square mile per day, would be

ample for the city if drawn directly from the river. If the river were tapped far enough up for a gravity supply, its capacity would not be sufficient. The Perkiomen Creek is not available for more than 95,000,000 gallons, and even adding the supply from other tributaries, it would not be possible to obtain a sufficient quantity from it in time of drought, as the drainage area is not sufficient. Storage basins may be large, but the water in them will most likely be kept low. The area of the Schuylkill Valley is 1800 square miles, and contains a population of 400,000. The refuse from the towns of Reading, Pottsville, Phœnixville, Norristown, etc., eventually finds its way into the river. The river is fed by thirty-five creeks, and four towns use it to carry off their sewage. It is not pleasant to contemplate the fact that we are to drink water polluted in this way. If we adopt the plan of only filtering a part of the supply, a double piping system will be necessary, and perhaps a double pumping system. The quantity of water pumped in 1891 was about 55,000,000,000 gallons, of which 11,000,000,000 were by water-power and the balance by steam-power, the latter only being reliable. The objections to the Delaware water, I think, cannot all be sustained, preference for the Schuylkill being probably more a matter of cost than anything else. The waste in the use of water is undoubtedly very great, and would be prevented if the consumer were charged by a meter record. One of the advantages of a double supply system would be that one supply could be kept under pressure, with great benefit in cases of fire. Enough data is now on file in the Water Department to keep a commission of engineers busy for a couple of years without making any new investigations, but no use has yet been made of it. If one of the many plans proposed were adopted, we might have a satisfactory supply in a short time.

Mr. Edward Hurst Brown: Has an underground supply been considered—such a one as is used, on a small scale, I believe, for the Mint?

Mr. Amasa Ely: If a gravity supply were adopted, it could be carried from one to another of our present reservoirs, starting with the northernmost, as their elevations increase with their distance northward. I believe that the Department has been

investigating a gravity supply with a view to better service. It might come from the Lehigh, Schuylkill, upper Delaware or tributaries.

Professor Silas G. Comfort: With regard to filtration, no filter will long remain germ-proof. The Pasteur filter is said to be absolutely germ-proof, but it must be re-sterilized by heating to 212 degrees Fahrenheit every three days. Even then, examinations after long periods of use might show the tubes to contain certain comparatively harmless bacteria which are not destroyed at a temperature of 212 degrees. Is there any system that will permanently purify water?

Mr. George V. Cresson: I believe the consumer would oppose the introduction of a meter from the excessive cost of water by meter, but would not oppose paying reasonably for the water that he used.

Dr. H. M. Chance: If Delaware water produces typhoid fever in the wholesale manner shown by Dr. Leffmann's figures, I think the continued pollution of the Schuylkill will soon make its water as bad. The towns on the latter river at present have no sewerage systems, but with their growth they will undoubtedly use the river for sewage disposal. A trip along its banks in the vicinity of Norristown and Phœnixville will convince any one of its present bad condition. There are the same objections to the source proposed by Mr. Thayer, as the towns along the banks of the Lehigh are growing and have the same practices. Dr. Leffmann has given a resumé of nearly all methods of purification, but I would like to ask him whether a method of boiling water on a large scale has been considered. To be efficient, a system of purification should not only decrease the bacteria in water, but entirely destroy them, and I should think "wholesale boiling" might do this. I think subsiding reservoirs are almost as objectionable as uncleaned filters.

Mr. James Christie: We would also need to know the probable cost for coal, etc., in such a system of boiling.

Mr. Edward Hurst Brown: In England, a parliamentary "Pollution of Rivers Act" has been adopted to prevent such contamination as is occurring in our rivers. Manchester is now experimenting on carrying its sewage in railway tank cars some

distance away to utilization farms. To be effective in our case, preventive legislation should be adopted by the State.

Mr. Ostrom (*Visitor*): I think that the double supply system would be a good one, as it would make the house supply independent of street use. The question of the cost of the best system should not deter the engineers if the citizens do not object.

Professor Silas G. Comfort: Dr. West's sterilizing system, with which I am acquainted, first filters the water and then boils it under pressure to from 212 degrees to 230 degrees. It is passed through a heating chamber (the heat being supplied by hot water, which passes around the heating chamber from the water back in the range) into an air-tight storage reservoir or tank on the lower floor of the building. The compressed air in the tank, due to the city pressure in the water pipes, forces the water to the upper part of the building. A thermal valve in the heating chamber prevents the water from passing until the desired temperature is reached. In the case I have in mind it has worked very satisfactorily and the water seems to be thoroughly sterilized.

Dr. H. M. Chance: I believe this to be a good system, but probably too expensive for use on a large scale.

Mr. John Birkinbine: There is scarcely a stream which drains fifteen square miles of territory, and which enters either of our river systems within fifty miles of Philadelphia, which I have not traveled from source to mouth, investigating its availability as a contributor to the water supply of Philadelphia. Some of these reconnoissances (and in addition, actual surveys made of prominent sources) resulted in a recommendation by my father that Philadelphia should utilize the drainage area of the Perkiomen Creek as a water supply which should be introduced by gravity. Had this recommendation been accepted, it would have been greatly to the advantage of Philadelphia, and the plant proposed would probably have been more than sufficient for the city to-day. What would have been good medicine for Philadelphia twenty-five years ago may not be necessarily sufficient for the city of to-day, and had this plan been adopted the authorities might soon be called upon to employ some of the additional sources of supply contemplated by the original plan.

Philadelphia is a great city, and it cannot afford to do anything by halves. The question of a water supply must therefore be approached in a liberal spirit, free from prejudice either as to source or method of supply. The suggestion made by the Director of Public Works, for a Commission, is a good one. As I understand the proposition from reading it in the public press, the Director proposes to submit all the data on file in the Water Department, for which the city has expended a large amount of money, as well as all of the suggestions and plans which have been submitted by others (and some of these have been very carefully prepared), to the fair, unbiased consideration of the Commission. These gentlemen are to collate and analyze the accumulated data, presenting the result of their study in a report, which, presumably, will give a recommendation of what they believe to be the best method, or possibly a comparison of several available methods. Such a report should guide our city officers in determining the course to be pursued, and also educate the people to sustain the Mayor and Councils in their action.

But even if the report of such commission were in hand to-day, and a plan adopted by Councils, the consummation of the work would take years, and, pending new constructions, the present sources of water supply must be depended upon. Therefore, it behooves us to consider the sanitary conditions of these sources, and to take means of preserving their purity. The question of how far pollution can be controlled by legislation is as much a problem for lawyers as for engineers, but a rigid enforcement of existing laws will undoubtedly do much to relieve us of many of the unpleasant features in the drainage area of the Schuylkill Valley.

We must remember that as the anthracite coal fields are exploited, as mine workings are deepened, as the economies of coal preparation by washing and jigging are introduced, an increase in acidity in the water coming from the coal regions is to be expected, but this may, in turn, be to our advantage, as the acid water receives no neutralizing agents until it reaches the Ontaulanee, the Tulpohocken, and other limestone streams in the vicinity of Reading; and it is probable that the acid in the water

is sufficient to destroy, or at least to greatly modify, the injurious effects of the present drainage from Reading, and possibly as far south as Pottstown. If the acidity of the water should be marked below Pottstown, sufficient limestone areas exist in the neighborhood of Norristown and Conshohocken to neutralize this. Notwithstanding these self-corrective features, there is much in the water of the Schuylkill to make the consideration of it as a beverage unattractive.

As the towns along the river grow in size and importance, they will follow the action of Reading, which, after using its own soil to filter the water which passes into the river, is now constructing a system of sewers. As sewers are built we may expect a material increase in the deleterious matter carried into the river, not only by the augmented population, but because this matter is delivered directly into the water-course without any natural filtration, and also because its volume will be greatly increased by the appliances introduced into houses and other buildings for removing all accumulated impurities.

Without attempting to answer the question raised by Dr. Chance concerning the possibility or practicability of boiling all or a part of the water to supply the city, we may safely assume that if a Board of Health consider this necessary for all of the water used for personal purposes, such portion of the supply could be boiled by the city in quantity at less aggregate cost than by each individual consumer, and this brings up the suggestion of Dr. Leffmann of having two systems of supply. The idea of independent systems is not as impracticable as it seems at first sight. Suppose our present pipe system were connected with a supply of satisfactory water for domestic and personal use, and the fire hydrants, except in the business and manufacturing portions of the city, were also supplied from this source. Now the bulk of our business houses and manufactories, although considerably scattered, cover but a limited portion of the area of the city, and it is in this portion that most of the large fires occur. If a secondary system were introduced, so as to supply water for manufacturing, elevators and fires in the industrial districts, its cost would not appear to be prohibitory, and it would be capable of further extension from time to time. This

is merely a suggestion brought out by Dr. Leffmann's paper, and is one of the problems which will doubtless be considered by any commission.

The suggestion made by Mr. Thayer, of pumping water from the Lehigh River, above Allentown, into the Perkiomen Creek, and allowing it to flow down the bed of this creek, will necessitate again pumping the same water, and appears to neglect the value of the elevation, which would furnish a partial gravitation supply. It would be unfair to condemn Mr. Thayer's scheme with no other information than the map and brief data offered, but it does not give indications of merits to compare with some others which have been suggested. If I correctly understand the proposition, there would be little, if any, improvement in the character of the water taken from the Lehigh River at the point selected, over what could be obtained from the Schuylkill River in equal quantity; and utilizing the bed of the Perkiomen Creek nearly to its mouth would demand the control of a larger area of the water-shed than if this stream were used for a gravitation source of supply, supplemented, if necessary, from the Lehigh River.

One thought more; in considering the use of water for manufactories, we must remember that one of the causes of our industrial development has been that the city furnished water to manufactories at a low rate, and in any scheme for the improvement of the water supply this should be borne in mind. Philadelphia cannot afford to put an excessive tax on the manufactories consuming water. It is well to measure the water, but the charges for volume should be placed at a minimum.

Mr. Edward Hurst Brown: I recently called attention to the necessity for legislation to prevent the contamination of the water supply, which I think is very necessary in the case of the Schuylkill River. There is a plan on foot, I understand, to build one more manufacturing town on that stream, and its promoters seem to have very lax ideas as to the harm they would do by using it to carry off their sewage.

Mr. E. F. Smith: In discussing the able and interesting paper on the Water Supply of Philadelphia, read at our last meeting by Dr. Leffmann, I desire to confine my remarks mainly to one

thought, namely: "That the consideration of the water supply of Philadelphia has generally involved the proposition for a new source, it being assumed that the Schuylkill River is absolutely unavailable both as to quantity and quality."

The Schuylkill River is now, and must, by force of circumstances, continue, for a considerable period of years, to be the main dependence of the city for its water supply. A work of such magnitude as an entire change of base of the water supply of a city of over one million inhabitants, involving the acquiring of sites for impounding reservoirs, the obtaining of the right of way, and the construction of aqueducts to bring in a supply from a distant source, requires years for its execution. In the hands of the municipality, hedged about with legal forms and restrictions, it might even be the work of a quarter of a century, if we may judge by the time required to erect and furnish a single public building, of about equal cost with a new water supply, and which, begun sixteen years ago by the city and prosecuted uninterruptedly ever since, is not yet ready to receive its Common and Select Councils.

As a matter of fact it has already taken twenty-five years (1867–1892) to discuss the question of a future supply without coming to a conclusion. How much longer will it take to reach that conclusion and execute the plans?

In 1867, when the agitation of this question took shape in the appointment of a Commission, the river at Philadelphia was in a worse state of pollution, particularly in Fairmount Dam, than it is now. Twenty-five years have elapsed; the city has increased enormously in population, whilst at the same time the death-rate, the surest index of the condition of the water supply, has not increased.

The obvious reason is that much has been done in that time, and particularly in the last ten years, to improve the supply by diverting from the river well-known sources of pollution within the city limits.

Assuming that the city will be forced to depend mainly upon the Schuylkill for its supply of water for household purposes for another twenty-five years at least, I will address myself to answering the assumption that this supply is "absolutely unavailable both as to quantity and quality."

A recent article published in a morning newspaper (*The Ledger*, November 2d) said: "The flow of water in the Schuylkill River has been gradually reducing in volume while the consumption has been rapidly increasing." "The minimum flow in summer is now less than half of what it was a half-century ago, according to statistics in possession of the Water Bureau."

It is questionable whether there has been any very marked change in the minimum flow of the river in the past fifty years. The statement emanating from the Water Bureau is evidently based upon figures published in the early reports of the Schuylkill Navigation Company, that the minimum flow about the year 1816 was 400,000,000 gallons in twenty-four hours. That was reported to be a float measurement, but there is no means of knowing whether it was the minimum flow or not. The minimum flow of a stream cannot be taken from one isolated measurement. It should be the minimum of the natural flow of the stream for twenty-four hours, selected after careful gauging, from observations extending over a long period of years.

The minimum flow in	1869	was, approximately,	250,000,000	gallons.
" " "	1874	" by measurement,	245,500,000	"
" " "	1881	" by comparison with 1874,	225,000,000	"
" " "	1892	" by weir measurement,	210,000,000	"

The minimum flow, 210,000,000 gallons, was reached this year during a few days only during the month of November. The average daily flow during the season of drought was about 250,000,000 gallons.

If the decrease has been only 15,000,000 gallons as between the two lowest measurements found in the past twenty-three years, it is not possible that there should have been a difference in the minimum flow of 190,000,000 gallons in the past fifty years.

Such figures are mere guess-work, and ought not to be entertained, because they are alarming to the general public.

The city, during the drought just ended, used nearly all the water that flowed down the river, but it was not pumped for the use of consumers in the city. When the drought was the most severe and the flow of the river was at its minimum, a large part of the consumption by the Water Bureau was for power at the Fairmount Works, where turbine water wheels are employed, at

an expense of not less than twenty gallons for power to one gallon pumped into the reservoirs. During the extremity of the drought this use of water for power alone amounted at times to over 100,000,000 gallons per day.

The city has not yet reached the point where it can be said that the Schuylkill River is deficient in quantity to supply her needs; with 100,000,000 gallons a day to spare in the natural flow of the stream in seasons of extreme drought, to say nothing of the 4,500,000,000 gallons stored in the dams on the river above Flat Rock, there is little fear of a water famine for many years to come.

But the point which I wish to emphasize most is as to the quality of the water. In the discussion which followed the reading of Dr. Leffmann's paper it was stated that the Schuylkill at Philadelphia receives the sewage from a population in the valley of over 400,000 people. This statement may have been made inadvertently; nevertheless, it has been constantly asserted in the public journals that the sewage from a population of 250,000, with hundreds of large manufactories, drains directly into the river. These figures are entirely too high. There is no such population as 250,000 contiguous to the river Schuylkill and its tributaries, or dwelling so near as to drain into it. It will not be contended by any reasonable person that the drainage from farms in the open country, away from all water-courses, finds its way into the river.

The aggregate population of all the towns in the valley, including Pottsville and vicinity, one hundred and six miles by river from the city, is about 135,000 souls, a little over one-half the usual estimate. With the exception of that borough, which has one sewer, there is not a regularly sewered town in the Schuylkill Valley outside of Philadelphia.

The sewers referred to in the city of Reading as now building are drains for storm water, and not house sewers. That city has lately taken steps to build a sewerage system for house purposes, but instead of discharging the sewage into the river, the plan involves pumping to a point about three and one-half miles outside the city, where the sewage disposal works would be located; far away from the river and with only a remote possibility of any contamination of the stream following.

In a former paper on this subject, which I quote, I made the following statement: The flatness of the valley south of the Blue Mountains, and the fact that the river is bordered on either bank by railroads which form barriers to direct drainage into it, is an additional reason against the easy pollution of the stream. There are comparatively few improvements between the lines of railroad and the river, except within the limits of the large towns.

We have, therefore, the towns of the lower valley, from Norristown down, remaining as a menace to the purity of the water supply of Philadelphia, and it must be admitted that to a small extent they do pollute the stream, but only to a small extent, for the reason, as I have said, that they are not at the present time sewered.

The city of Reading takes the major portion of its water supply from the Maiden Creek, the second largest tributary of the Schuylkill, near the point at which it flows into the river. It has, therefore, practically a Schuylkill River supply. The towns of Pottstown, Phœnixville, Norristown and Conshohocken also draw their water supply from the river.

For a long time to come, therefore, it will be cheaper for the towns in the valley to keep the sewage out of the river than it will be to go to distant and doubtful sources of supply, and this can readily be accomplished by adopting the separate system of sewage as has been designed for the city of Reading.

I have no doubt, as Dr. Leffmann intimates in his paper, that a ride along the banks of the Schuylkill will show that it receives a large quantity of most dangerous matter; but, unfortunately for the arguments of those who condemn the Schuylkill, this is mainly the case within the city limits alone. The most dangerous sources of pollution are within the city of Philadelphia, and within five miles of its pumping stations.

Above Norristown the valley is much cleaner. The towns are further apart. The river flows through an agricultural district, fairly wooded, and the banks of the stream are clean, at least as clean as will be found on any stream of its size, not excepting the Delaware.

Considering the fact, therefore, that the Schuylkill River is

now and must be for a considerable period of years, the principal water supply of Philadelphia, it is worse than folly to condemn it in such a wholesale manner, and more especially to charge evils to the stream which have no certain existence.

Mr. John Birkinbine.—While in many features Philadelphia is noted for its patriotism and public spirit, we must admit an ultra-conservatism which interferes with carrying out some much-needed public improvements; and it is fortunate that this discussion has kept aloof from the advocacy of specific plans for the future water supply; for the first consideration is to educate a public sentiment which shall meet the necessary expenditures for a comprehensive plan. When Philadelphians will encourage the erection of a complete system of works, just as the citizens of New York, Boston, Chicago and other cities have done, we may expect to see our water supply improve.

We are probably to-day exhibiting more generosity than ever before in the erection of new reservoirs and pumping engines, and the increased storage capacity with which the city is now being supplied is helpful; but to supplement this, additional pumping capacity is demanded. If I understand the present position aright the new pumping machinery already contracted for is about equal in capacity to the Fairmount water-power pumps, *i. e.*, in times of drought, such as we have lately passed through, the city could be only supplied with as much water from the steam pumps alone as the present combined steam and water pumping capacity can deliver. During the late drought the water supply has hardly kept pace with the demand, and citizens were requested to restrict the use of water, not because the quantity flowing was insufficient, but because every steam pump was worked to its full capacity, and there was nothing in reserve. Some of the pumps need repair badly, and yet they dare not be stopped to make such repairs. Others have been in use for a number of years, and natural deterioration is affecting them. It is probable that if our city authorities were to decide to add a 25,000,000-gallon pump each year, the water supply would not more than keep pace with the increased demand and make up for the wear of machinery; therefore, whether the Schuylkill River remains the source of supply, or whether some

other source is selected, a liberal expenditure for a comprehensive plant is demanded, for pending the determination of the future plan and the execution of its essential features, we must depend upon our present source of supply—the Schuylkill River; the protection of this, and, if possible, its improvement, is therefore of primary importance.

The statement made by Dr. Leffmann, that sanitation is largely an engineering problem, is undoubtedly true, and yet, as engineers, we should recognize the great help which is given by the research of the chemist and the bacteriologist. Undoubtedly, the best way of determining the character of the deleterious matter in a body of water is to note what flows into it; but to the chemist we look for a quantitative determination at the point from which the water is taken for consumption. There is undoubtedly great value in a system of policeing a source of water supply, and thus keeping away much injurious or questionable materials, and this is preferable to constructing filtering plants or resorting to artificial means of purification. It is possible that for our present system of water supply it would be wise to use all of these means.

One of the serious defects of the Schuylkill River as a source of supply has been brought about by the filling up of the various pools formed by the navigation dams. I doubt if the pool of Fairmount Dam contains over 70 per cent. of the volume of available water that it did thirty years ago. Surveys made in 1861, 1864 and 1866 of this pool showed that during an interval of five years in the section between Columbia Bridge and Fairmount Dam (a distance of 8,750 feet), with a water surface of 168⅓ acres, the deposit from 1861 to 1866 amounted to 9,956,270 cubic feet, equivalent to a daily average deposit of 5,430 cubic feet or 201 cubic yards. In the same time (from 1861 to 1866) the water surface in this section of the pool was reduced 1,576 acres, or 3.15 acres per year. What the deposit amounts to at present, we can only conjecture; but all of this was preventable, as this accumulation occurred within city limits, and under the jurisdiction of the Park Commissioners. Instead of a liberal settling pool and storage reservoir, we have merely a water channel. I have not the data to show how these figures correspond with

those of other pools on the Schuylkill River, or to what extent these have been reduced in area and capacity.

It is doubtful whether if we allow for interest on first cost, water can to-day be pumped by water power at Fairmount as cheaply as by steam at the other works.

The *per capita* consumption of water, as shown in the Annual Report for Philadelphia, is undoubtedly very high, but I very much doubt whether the real consumption is over 85 to 90 per cent. of that reported. This is not a reflection upon the official report, but remember how many pumps are at work, with the chances of defective valves, and the failure of some of them to make the stroke estimated for them, and the chances for loss at these points as well as at glands, joints, etc., would point to a large volume of what is officially credited to the pumps which never enters the pumping mains. Then the absorption from the surface of the reservoir, the leakage from some of them, reduce the volume of water to be supplied to the city. After allowing for the losses beyond those properly estimated by the Water Bureau, due to the operation of the pumps, which are kept continuously at work with little chance for repairs, for losses in pumping mains and reservoirs, we have the leakage from a thousand miles of distributing pipes. Scarcely an excavation is made in this city along any of its streets, but what the leakage from gas mains is made apparent. While the water mains are laid with more care than the gas mains, some of them are very old, some have been undermined during excavations made subsequent to the time when they were placed in the ground, others have been subjected to strains, and numerous causes tend to jeopardize the perfection of the water-pipe system. If we make allowances for the insertion of stop valves and necessary branches for cross tees, and fire hydrants, there are probably over half-a-million joints in this system of distribution, and there are on it probably 15,000 stop valves and as many or more fire hydrants; add to this the private connections to probably 400,000 dwellings and other buildings, and the defects of plumbing up to the house valve, and we have so many opportunities for leakage that the aggregate is undoubtedly large, and it is questionable whether over 85, or at best 90 per cent. of the water properly es-

timated as being pumped reaches the consumer. A water supply which has grown with the city, which embraces an old plant patched by numerous additions, cannot be expected to deliver as large a proportion of the water as could be obtained from some general plan which was planned and carried out in its entirety.

I was not aware that the sewers now being constructed by the city of Reading were to be carried to a utilization farm, but it may not be out of place to quote some statistics which, though old, are startling: "The Board of Health of the city of Reading, in their report for 1876, estimated the quantity of animal waste accumulating in the limits of the city in twenty-four hours, to be 2.51 tons of excrement, 25.14 tons of urine, 154.28 tons of liquid garbage. The population of the city at that time was 40,100."

The question for us is how much of this material from a city, which has grown, and is still growing, will reach the Schuylkill River.

I differ from Dr. Leffmann in his views concerning the protection of reservoirs from intrusion, believing that the safer plan to follow in harmony with the policy of moneyed institutions, who now keep banking houses brightly illuminated at night, as a better protection than any other means.

There are seldom good grounds for the anxiety concerning the amount of deposit to be found in a reservoir. The almost universal result of cleaning a reservoir is that the small amount of mud in it is a surprise.

There is no question but what some of the plans which have been suggested for the improvement of our water supply are based upon selfish motives, but this fact should not interfere with a fair investigation of any merits these may possess. If the city of Philadelphia needs an improved water supply, and its authorities will not undertake the introduction of such, or if the people will not sustain its officials in securing such supply, we can hardly blame individuals who see a possible profit, or other personal advantages, for drawing attention to schemes which as far as these persons are concerned are selfish; but all such propositions should be fairly and frankly investigated, to determine their value to the city, and such I understand is to be the duty of the commission which has been suggested.

Mr. C. H. Roney: In about 1869, I believe, the first survey of Fairmount Pool was made, and large deposits of sediment were found, containing organic matters and evolving combustible gases. My observations at that time led me to believe that it would be necessary to add another source than the Schuylkill for our supply, and that the upper Delaware would be, perhaps, the most feasible.

Estimates were made between 1870 and 1880, that placed the cost of bringing the supply from the upper Delaware at about $25,000,000.

The suggestion to boil the supply, if it were required to raise the temperature of the water about 167 degrees Fahrenheit, from an average of 45 degrees to 212 degrees, would require theoretically about 6,800 tons, say, 7,000 to 10,000 tons of coal to heat 100,000,000 gallons per day.

Dr. H. M. Chance: That answers my question in one way only, and is correct if we assume the water would be delivered to the reservoirs hot.

With regard to artesian wells, in my opinion, they could not supply one-tenth of the city's needs. The underground strata here do not contain water-bearing rocks, and no greater quantity could be obtained from wells than now flows into the streams draining the same region.

When the Schuylkill is low the water flows slowly, is fairly aërated, and is of reasonably good quality, but at flood it scours out filth which has accumulated in the slack-water pools, and sewage from the towns above is quickly carried toward the city.

If the water for boiling was taken from the river at say 56 degrees, and discharged from the apparatus at 60 degrees Fahrenheit, it would require a much smaller quantity of coal per day than that figured by Mr. Roney. All of the water can be heated by the latent heat of the exhaust steam from the pumps. I have constructed a small apparatus which demonstrates this, and a large one could be constructed on the same principle for about $1,000,000, to sterilize the supply for this city.

Mr. John Birkinbine: High-pressure pumps would require more coal than low-pressure ones, and the saving mentioned by Dr. Chance would, therefore, not be very great. Would it not be

better to consider the possibility of boiling the domestic supply only?

The proposition for protecting our reservoirs from intrusion I think unnecessary, as I have cleaned several reservoirs and have in every case found a smaller deposit of mud than had been anticipated.

Mr. Edwin F. Smith: An Ordinance has been passed by Councils of the city of Reading, to build a system of house sewage on the Waring principle, so that pollution may be kept out of the river. The intention is to locate the sewage disposal works at a distance of three miles from the river.

Mr. John E. Codman: What Mr. Smith has said about the Schuylkill supply is in accordance with observations that have been made by the Water Bureau. In October of this year, the rainfall varied in Eastern Pennsylvania as follows: Philadelphia, .32 inches; Lebanon, .29 inches; Reading, .20 inches; Doylestown, .17 inches; Pottstown, .32 inches; Quakertown, .63 inches; and Seisholtzville, .61 inches. With the present storage capacity slightly increased, our future needs would be amply provided for, and if we could control the matter of sewage disposal, the Schuylkill River would be a very good source of supply. If a gravity supply could be obtained in sufficient quantity, it would, of course, be superior to one that had to be pumped.

Dr. H. M. Chance: I do not think the adoption of the Waring system at Reading will be of much benefit, as it merely filters the sewage, and does not remove the danger of pollution.

Mr. Harvey Linton (*by letter*): The improvement of the present supply by all the methods suggested will be necessary if the Schuylkill is not to be abandoned. It remains, then, to compare the cost of this improvement added to the present system and the cost of a gravity supply. Perhaps, if quality be considered, the upper Delaware would command a higher price than the improved Schuylkill.

Mr. James Christie: There is no doubt that wise legislation could do much without trespassing on the rights of individuals. Water could be saved in many manufacturing establishments by the dry method of sewage disposal, which has been proved perfectly practicable.

Mr. Howard Murphy: Very active measures are being taken to secure legislation, giving the State Board of Health police jurisdiction over the streams in this Commonwealth for the purpose of protecting them from contamination, and to confer on sewerage companies the rights of eminent domain.

Dr. Henry Leffmann: As has already been mentioned, I feel sure that artesian wells would not furnish a sufficient quantity of water; and, furthermore, its quality would not be suitable. I feel very much gratified that this important subject has excited so much attention, and think that something will soon be done to give us a better supply.

III.

HIGH SPEED ON RAILWAYS—FROM A MAINTENANCE OF WAY AND ENGINEERING STANDPOINT.

By Chas. S. Churchill, Active Member of the Club.

Read December 3, 1892.

In considering the subject of high speed on railways, a writer of undoubted authority on the locomotive has recently made the statement that in his opinion a locomotive will be produced in a few years that will attain a speed of one hundred miles per hour, and that this speed will be secured on our railroads. A second writer on the same general subject, acknowledging the possibility of the construction of such a locomotive, has taken the ground that the speed actually attained on our railroads will, after all, be limited by the means given for protecting trains. In substantiating this statement he showed the difficulty in stopping trains at such high speeds within a reasonable distance, thus making necessary the placing of all signals at a much greater distance from the danger point than is required by the best practice of this time. A third writer, also an undoubted authority on the locomotive, while acknowledging that a locomotive may possibly be produced in a few years that will attain a speed of one hundred miles per hour, has pointed out the enormous resistance to be overcome by a locomotive and train traveling at such a speed, and the consequent small amount of paying traffic that such a locomotive will be able to handle. This writer at once calls attention, therefore, to the necessity of making an improvement in the track of the present day in order that the great resistance may be in part overcome and in order that trains may travel with safety at such high speeds. The fulfilling of these requirements are all purely engineering matters.

In considering these matters fully we must answer the question: In what manner must a railroad be constructed in order to allow of the passage of trains at a speed as high as one hundred miles per hour, with safety? The answering of this question

leads us to criticise many of our present plans of construction and methods of maintenance, and leads us further to consider in what way and to what extent improvements can be made to the best track of this date.

With the above requirements given us we must determine the allowable grades, the allowable curvature, the form of roadbed, construction of bridges, etc., necessary arrangement of tracks and the construction of track in all its details.

Undoubtedly a locomotive intended to travel at any speed from eighty to one hundred miles per hour, must be considerably heavier than any at present in service; certainly the loads on the drivers will be heavier. Further than this, the passenger equipment intended for this special service will be heavier than any at present in service. Consequently, the roadbed and track must be provided to meet not only the increased speed, but also the increased loads.

An examination of the tractive power of locomotives at different speeds shows that only a very small portion of the load at present hauled at a rate of 50 miles per hour, can possibly be hauled at the rate of 100 miles per hour on a level and straight track. With the introduction of grades and curvature, this small fraction is still further very rapidly reduced. A large portion of railroads in this country, including the best trunk lines, have grades in excess of 30 feet per mile, and have curves in excess of 3 degrees. It is very evident, therefore, at the outset, that very few of the railroads in this country are equipped with either grades or alignment that will meet the requirements of such fast service as 80 or 100 miles per hour. Let us, therefore, start at the foundation and build our railroad as above outlined in a general way.

Grades.

Whatever may be the power of the coming locomotive, the capacity of the road is governed in a great measure by the maximum grades of the road. Even if the locomotive has power to run at a speed of 100 miles per hour on a level and straight track, the introduction of a grade of 20 feet to the mile would reduce the speed of the train to 80 miles per hour, and a heavier grade than 30 feet per mile would bring the speed of the

train down to one often reached on our trunk lines of this day. It is evident, therefore, that our grades must be fixed at the outset at 20 feet per mile, with possibly a ruling grade in exceptional cases of 30 feet per mile.

The adoption of these grades immediately indicates that high-speed railroads will not be located across mountain divides, but will be confined to more level sections. Such grades can be readily secured, however, in many portions of the country traversed by our trunk lines at present, such as portions of Maryland, Delaware, New Jersey, Pennsylvania, New York and the New England States, also in the section west of the Alleghanies and north of the Ohio River. However, through rolling country very heavy work will be required. Still this work is in the direction of improvements now being made by several of our best trunk lines.

Curvature.

Resistance due to curvature is always measured by an equivalent grade. It is evident, therefore, that this is the next item of importance. The addition of a 1° curve to a line adds resistance equivalent to a grade of two feet per mile, and the resistance increases as the curves are sharpened. It is impossible, however, to get along without curves; but these curves should be made as small as possible and the grades should be reduced at the rate of 0.04 per cent. per degree of curve. This equation of grade for curvature at once removes the extra resistance due to their use; but there is another question to be considered which limits the use of sharp curves in a line designed for a speed of 80 or 100 miles per hour. It is now the practice to reduce speed on sharp curves in order to avoid danger from centrifugal force throwing the body of the car to the outside of the curve, or producing a swaying motion of the car, thereby causing danger of derailment. In practice, therefore, our speed is very greatly limited by the sharpness of the curves, and the curves cause a loss of time and prevent smooth riding track.

A 5-degree curve probably causes 50 per cent. more wear to the rails than is produced on a tangent, and there is an item of danger in sharp curves not existing in those of less degree. If a

speed anything like 100 miles per hour is to be maintained, therefore, curves should not generally be used sharper than 1 degree and no curves should ever be used sharper than 2 degrees.

Roadbed.

The adoption of grades never in excess of 30 feet per mile and of curves never in excess of 2 degrees will cause heavy work in construction wherever the road may be built. It is already found that for high speed service four tracks are necessary, and certainly any section of the country requiring a speed as great as 80 or 100 miles per hour, will furnish not only a large passenger business, but also a large freight business, and high-speed passenger service must be kept on tracks separate from the freight service. This makes evident at once the necessity of a four-track railroad.

Tracks should be placed at least 13 feet center to center, with ditches along the outside tracks at least 7 feet from the edge of the rails, and the slopes of cuts and fills in earth-work should be $1\frac{1}{2}$ to 1, and all the earth cuts should be thoroughly sodded. Rock cuts should be taken out at a slope of $\frac{1}{2}$ to 1 and be thoroughly cleared of all loose material. Loose rock cuts should be taken out at a slope varying from $\frac{1}{2}$ to 1, to slope of 1 to 1, as the material may require for stability. Berm ditches should be provided at the top of all cuts. In fact, every precaution must be taken to protect the roadbed intended for a high-speed railroad.

Preferably, for safety at least, the freight business should be handled on the outside tracks, and the two middle tracks should be retained for passenger business. Tile drains should be placed in cuts between the passenger and freight tracks, to thoroughly drain the roadbed under the passenger tracks. All embankments should be carefully built of material taken from the cuts, carefully placed at a slope of not less than $1\frac{1}{2}$ to 1. The edge of the roadbed should be limited by a line 7 feet from the outside rail of the freight tracks. No open culverts should be allowed in any case, and all culverts, whether box culverts or arch culverts, should be laid in good cement and should be of ample size to care for the water-sheds. In no case should any culvert be built

without having first measured the water-shed, to determine its size. No farm road, highway or street should be crossed at grade, as at the proposed speed it would be practically impossible to give the necessary warning to people crossing the tracks. It would further be impossible to check the speed at every street or highway. Finally, as a further safety to the traffic, all of the right of way should be substantially fenced, the posts of such fence being not further apart than eight feet.

Bridges.

The location should be so made as to avoid the necessity of draw-bridges.

The grades should be arranged with a view of using stone arches over streams, farm crossings, highways and streets wherever it is possible to secure them. A little investigation will show that stone arches are after all about as cheap structures as girder bridges built to carry such rolling loads as are now required; and if in remodeling an old road, cases are comparatively few where stone arches cannot be substituted for open bridges, certainly there will be still less reason for open bridges in the case of a new road constructed with this end in view.

Wherever for some particular reason it is impossible to build a stone arch bridge, plate girder bridges with buckle-plate floors should be used up to a span of 100 feet. For various spans requiring truss bridges, riveted trusses are preferable, at least up to 120 feet span, and pin-connected trusses for spans above this. All these bridges, however, should be provided with buckle-plate floors.

Ballast.

The ballast should be preferably broken limestone or trap. In absence of these materials, sandstone will answer, or slag carefully selected will produce good track. The thickness of the ballast should never be less than 12 inches under the tie at the center of each track, and no stone should be used for ballast larger than will pass through a $2\frac{1}{2}$-inch ring.

Track.

Having formed a roadbed on light grades, light curves and substantially built, the effective results are after all to be secured

in our track; hence, every detail must be critically examined in order that all possible cause for undue resistance may be removed; and every precaution possible should be taken to secure safe travel.

Tracks should be spaced 13 feet center to center. Ties should be white oak, hewed to a thickness of 7 inches, and having a face 7 inches wide, each tie being 8½ feet long. 3,000 ties should be used to the mile, and never less than 2,800. As both the locomotives and cars used for this fast speed will be heavier than at present used, our track must be rigid, but not inelastic. Ties spaced as above indicated will assist in securing both of these ends; but our rail must be proportioned to the same principles. We are accustomed to design bridges by carefully calculating and limiting the strains in all its parts. There is no reason why our rails should not be designed on the same principles. At this day a large portion of our roads are using rails that are strained far higher than they should be. The rolling stock used on most of our roads to-day calls for the use of rail in weight about 85 pounds per yard. Undoubtedly, the failure to use rail having the proper section, and consequent rigidity, leads indirectly, and sometimes directly, to many accidents. A road intended for any higher speeds than those at present used, should be equipped with rails weighing 100 pounds per yard. It should have a good height in order to be rigid, and it should have a wide base in order that it may not cut too rapidly into the ties. A rail 5¾ inches high, with a 5¾-inch base and a head 2¾ inches wide, is one filling such requirements. About 25 per cent. of the accidents at present occurring, other than collisions, are due to bad track. These defects are generally either traceable to insufficient ties, defective ties, light rail, bad joints, or insecure fastening of the rail to the ties. At least 2 per cent. of such accidents are due to the joints themselves. Hence, the number of joints in our track should be reduced to as low a number as possible. Rail mills are now able to produce rails readily in 60 feet lengths, and there is no reason why rails of such lengths should not be used, thereby avoiding 50 per cent. of the joints in the track. An expansion of ½ inch is sufficient for a rail 60 feet long, and this space cannot be said to be a

serious objection, providing a secure fastening of the joints is furnished. However, much smoother riding track will be secured by the adoption of the mitre joint, *i.e.*, rails cut at an angle of 45 degrees. Such a joining (known as the Sayre Joint) has been in use on the Lehigh Valley Railroad for ten years past, and is a great success, and there are good arguments for the extension of this practice to other roads.

The form of splice to adopt for such a road is one of the most important questions. The fish-plate type of joint, at present so largely used, has been criticised by able writers, by engineering societies, and by engineers everywhere for several years. It is from its defects that many accidents are caused. It does not give sufficient support to the rail; in fact, it is defective in principle; and it is very certain that this form of joint is to be displaced within a few years, even with the present speeds. The fish-plate joint does not give sufficient support by its bearing under the head of the rail. The rail should be supported at the joint from beneath, as well as under the head. It is in this way only that a joint can be secured even approximately as strong as the balance of the rail; and no joint can be said to be safe unless this end is secured. The splice in use on the Norfolk & Western Railroad in connection with an 85-pound steel rail is similar to the splice illustrated in Vol. VIII, No. 4, of these Proceedings. Such a joint as this can be applied either to a mitred joint or to a square-jointed rail, and it is certainly the only form at present devised that can be said to be safe for a speed of 80 or 100 miles per hour.

The present use of spikes for fastening rails to the ties has the single argument in its favor that the fastening is quickly made. The fastening, certainly, is not secure, and is not satisfactory. The insecure fastening of rails to ties is, certainly, the indirect cause of many accidents. It leads to the use of rail braces often where rail braces would not be required if some other means than spikes were used to fasten the rails to ties. It is certain that the ordinary rail spikes will also soon disappear from the main tracks of the trunk lines, and especially if the speed is to be increased. The Bush Interlocking Bolt seems to be the simplest device for securing a very effective and rigid fastening of

the rail to the ties. This device, or some similar one, will be necessary on any railroad where speeds are used as great as 80 or 100 miles per hour.

A track ballasted in the manner described, provided with ties spaced as above noted, with heavy rails fastened by bolts to the ties, with half the number of joints at present in use, and with splices such as above described, having a strength practically as great as the rail itself, is the only combination of materials which will produce a comparatively smooth and safe riding track, and one which will avoid undue resistance to trains. The rails must be brought up truly level on tangents, the level-board and the track-gauge being the most important tools required by the track foreman. To reach such speeds as 80 or 100 miles per hour, the outer rails on curves of 1 degree and 2 degrees should be elevated 5 inches above the inner rail, or rather, the elevation is to be secured by depressing the inner rail and raising the outer rail each one-half this amount.

Across all through bridges the track should be protected by guard-rails on the inside of track, the clearance between the guard-rail and the main rail being 7 inches. Switches should be as few in number as possible. These are danger points on our roads, and the most approved pattern of point-switch seems to be the best device at present in service. Stiff frogs would hardly answer for high speed, and would be very serious danger points. Spring-rail frogs seem to answer the requirements from our present point of view. These frogs should, however, be of improved pattern; they should be built on a $\frac{3}{4}$-inch plate, the wing-rail should have the spring placed near the end, should have a lever to hold it in position, and the top of the wing-rail should be beveled to prevent a possible forcing open of the wing-rail by badly worn engine tires. The standard spring-rail frog of the Norfolk & Western Railroad is one of the best forms at present in use.

All switches should be guarded by distant signals, so placed that trains running even at 100 miles per hour could be stopped before reaching the switch, in case the signal was at danger.

Protection of Track.

In order to carry on traffic at any such speed as 80 or 100 miles per hour, all track must be constantly patrolled; an interlocking system of signals, perhaps preferably an electric system, would be found necessary to protect such high-speed trains. In fact, the possible running of trains at such speeds may after all, as one writer has stated, depend upon the ability of signal engineers to devise a means to properly protect such trains.

The above described railroad may be said to express a high standard towards which all railroads should aim, whether it be in order to maintain the present speed with an additional degree of safety or to secure such speeds as 80 to 100 miles per hour. It is a standard which may apply, to an extended degree, to an old road being remodeled and improved, as well as to a new one which may hereafter be built for fast passenger service.

The various details described are, it is true, open to discussion and criticism, and, above all, to future inventions and improvements. Whether such speed as 80 or 100 miles per hour will be secured in a few years or not, of some things we are certain, viz.: that the tendency at present is to constantly introduce heavier locomotives and heavier rolling stock, and to use constantly higher speeds. It is the duty of the engineer, whether he is on construction or maintenance, to so make his recommendations and plans that the road may be made safe for such a traffic, and certainly only such roads as are built or improved upon the plans above generally outlined, will be able to meet these requirements.

In Conclusion.

It is evident that no existing road, at least in this country, fulfills the above requirements; therefore, none of them are at present suitable for speeds of 80 or 100 miles per hour. Further, only comparatively few of our trunk lines can, from the nature of the country traversed, be brought fully to this condition. It is not very probable that a new four-tracked railroad will be built especially for such a high-speed service; hence, portions of existing trunk lines located in suitable sections of the country must be regarded as the only roads which may in time de-

velop a great increase over present speeds. Many such sections may be improved in grade and alignment so as to secure maximum grades of from 30 to 40 feet per mile, and maximum curves of 4 degrees; also, the abandonment of all grade crossings. This having been done, and the track having been brought up to the standard above outlined, a locomotive capable of hauling a train on a straight and level track at the rate of 100 miles per hour, may make on a properly protected line an average speed of from 70 to 80 miles per hour.

DISCUSSION.

Mr. John C. Trautwine, Jr.: In attempting to discuss Mr. Churchill's paper I find myself irresistibly drawn from the consideration of merely technical matters, such as the dimensions of spikes and the radii of curves, to that of questions of organic evolution.

Our highly inventive age abounds in instances where a device, constituting in itself and for its time a notable step in advance, has, in the process of evolution, become in turn a stumbling-block and a rock of offense.

It is not only in theology and in politics that we manifest our apathy by choosing rather to follow in the wake of our ancestors, or to adopt the complexion of those about us, than to be our own men and do our own thinking. The same indolent tendency marks our actions in lines more intimately connected with our personal every-day needs, and thus it is that we have often been found, and are still found, plodding patiently along in the ruts marked out by the requirements of our predecessors, ruts which for them were highways in the wilderness, but which have outworn their usefulness for us, and have come, in the march of improvement, to serve rather as snares and pitfalls.

The introduction of the stage-coach was, in itself and in its time, a valuable step in advance, yet to-day we see its stagnating influence in the inability, or, at most, the only partial ability, of our European brethren to outgrow their stage-coach form of railroad car.

The railroad, at the time of its introduction, offered an enormous increase in the speed of carrying mail matter, but one of the

results of this has been that we have come to regard the railroad in some sort as the divinely appointed means to this end, and that a half-ounce letter is to-day dragged across the continent in the same ponderous vehicles in which our clumsy bodies are still transported, instead of being whisked along in pneumatic tubes and literally with the speed of the wind.

This tendency to follow in lines already laid down is illustrated also by the edifying spectacle presented to Philadelphians of two steam railroads running occasional and heavy trains drawn by heavy locomotives to Chestnut Hill, while towns throughout this and other States connect themselves with points at similar distances by means of electric roads running single light cars at comparatively frequent intervals.

Radical departures from established precedent are the exception. As a rule we follow the easier plan of modifying, little by little, the designs bequeathed to us by our predecessors. And so the railroad naturally copied, so far as possible, its prototype, the common road. Curves were necessarily eased, grades were flattened, the wheels (or, sometimes, the rails) were provided with flanges, and other unavoidable innovations were submitted to; but in its principal features the new institution was, as its name indicated, but another form of *road.*

This could hardly have been otherwise under the circumstances, and even this much of innovation, which now appears to us so perfectly natural and inevitable a step, seemed, as we know, the height of madcap folly to the level-headed citizen of those days.

But while we may recognize this, and while we have abundant cause to be thankful for the system thus bequeathed to us, we may yet ask, especially in view of studies like this of Mr. Churchill's, whether that system is not even now nearing the limit of its usefulness. Instances of exceptional runs upon exceptionally fine roads, like those just quoted by our Secretary, can hardly be taken as proving that our average roadbed of to-day is fitted for sustaining speeds of eighty and one hundred miles per hour, with trains like, or heavier than, those now in use; and when we consider the enormity of the dimensions that will probably be required of roadbed and of rolling stock in order to

adapt our present railroad system to every-day working at these great speeds, the system seems threatening, like the militarism of Europe, to come to grief by reason of its very bigness.

Some further increase in speed will no doubt be attained with our present roadbeds, either as they are, or with such modifications as our "practical men" can tolerate; but when we reflect that a given train moving one hundred miles an hour possesses not twice but four times the energy of the same train moving at fifty miles an hour, and that this latter is already a severe ordeal for much of our present roadbed, we may well believe that so radical an increase in speed will demand a similarly radical departure from our present methods, a departure that only a visionary can regard with complacency.

I am inclined to think that the combination of machinery which will carry us at such rates as eighty or one hundred miles per hour (to say nothing now of those higher speeds which our children and grand-children will be morally certain to demand) will differ as radically from our present railroad system as the latter does from its predecessor, the stage-coach.

One idea which we have inherited from the institution last referred to, and which, I think, must be abandoned before we shall travel, as a rule, at eighty or one hundred miles per hour, is that the same roadway must serve for the transportation of both freight and passengers.

That we are beginning to outgrow this notion is indicated by the modern practice of reserving, on our principal lines, separate tracks for passenger traffic; and a good object lesson in this direction is the rapidly extending use of electric roads, devoted largely, if not exclusively, to passenger traffic.

It seems to me probable that when we have come to regard eighty or one hundred miles per hour as an every-day affair, we shall have abandoned the imitation of the stage-coach with its center of gravity several feet above its base, and that the vehicles will be hung from, rather than supported by, the rails (if, indeed, rails proper form any portion of the "road" of those days). If this is not the case, I think we may look to see an overhead contrivance to prevent lateral swaying.

At this stage of the proceedings it would be idle to attempt to

submit detailed drawings showing the arrangement of the transportation system of the future, but my own present conviction is that in that institution we shall have, instead of heavy trains dispatched daily or hourly, single light vehicles, following each other at comparatively very short intervals, such as every five minutes to New York, every ten minutes to Chicago, every half hour to the Pacific Coast. I cannot blame those who smile at these figures, but it may be in order to remind them that when the possible traffic between Philadelphia and Baltimore was estimated in advance at something like fifty or one hundred passengers per day, the suggestion was laughed to scorn.

I have before me a time-table of the Germantown and Norristown Railroad, dated November 18, 1867, or, I may say, exactly twenty-five years ago, at which time that road (then the *only* one) ran ten trains daily to Chestnut Hill. To-day the Pennsylvania alone runs thirty-eight trains.

If we admit the hypothesis of light vehicles passing at short intervals, which would certainly be vastly more convenient for the traveling public than our present heavy and infrequent trains, and if we grant also the entire divorce of the passenger and freight systems, we can then readily imagine a radically different and much lighter system of roadway, probably elevated above all possibility of grade-crossings and consisting, perhaps, of three or more, instead of but two parallel guides.

But whether or not these particular prophecies are destined to be fulfilled, I still believe that before we reach a steady diet of one hundred or even eighty miles an hour, our whole system of passenger transportation will have been fundamentally modified, so that it is perhaps hardly profitable now to speculate upon the dimensions which our present appliances would then have reached.

If even in this my views are chimerical, if we are to witness this great development of speed without a revolution in our present methods, I then think that we shall arrive at this by a process of very much the same sort as that which has brought us to our present speeds and our present dimensions, a process, namely, of evolution or of growth, rather than by a sudden leap.

From twenty and thirty miles per hour we have worked our

way rapidly, perhaps, but still gradually, to forty and fifty, from forty and fifty pound rails to eighty and ninety, from twenty and thirty ton to fifty and sixty ton locomotives; and it is in this way, I think, if at all, that we shall arrive at the proper dimensions for the great speeds now under discussion.

It is, nevertheless, of great interest to have the estimate of so capable and experienced an engineer as Mr. Churchill, as to what these dimensions may be expected to be.

Descending, therefore, from the foregoing rhapsodies, let us briefly consider this estimate in some of its details. As to grades, without going into the mechanics of the subject, it appears to me that if in the future we are to submit to the same proportional *variations* of speed as now, no material changes in grade will be required; thus, a grade which now reduces speed from fifty to thirty miles per hour, would then reduce a speed of one hundred miles to one of sixty miles; and if we are satisfied with a reduction of 40 per cent. in either case, the grade in question need not be flattened. In short, the matter of grades applies rather to *uniformity* of speed than to the speed itself. It must be borne in mind, too, that if the improvement of the gradients is obtained by lengthening the line, we may thus offset the advantage due to the gain in speed.

As to curvature; there is so much that is not known respecting the relation between curvature and speed, that I think it is only by guess-work that we can fix in advance the limit of curvature or the amount of superelevation required for these high speeds. Certainly, however, as Mr. Churchill says, such speeds will demand a lengthening of radii.

As to draw-bridges, it is difficult to see how these could in all cases be avoided, however careful the location. A navigable river, with low banks for many miles of its length, would seem to necessitate a crossing of this kind. Here, too, we must remember that a long detour to avoid a draw-bridge may involve as great a delay as would be entailed by the draw.

As to cross-ties, I am surprised to find that for the proposed heavier trains, and much greater speeds of the future, Mr. Churchill proposes to use, in ties, a quantity of wood per mile but little, if any, greater than that now in use, and this with a

diminished width of tie, which, it seems to me, would be apt to lead to disintegration of the ballast under such loads and speeds.

As to rails; under Mr. Churchill's proposed limitation of curvature to 1 degree and 2 degrees, his proposed 100-pound rails might possibly be found sufficiently heavy for the increased weights and speeds. Otherwise, bearing in mind that with a given radius the centrifugal force is proportional to the weight of the train and to the *square* of its speed, I should suppose that so slight an advance upon present practice would be found insufficient.

As to joints, I trust Mr. Churchill is right in saying that joints $\frac{1}{2}$ inch wide will be sufficient for his proposed 60-feet rails, for it seems to me that even such joints would give rise to severe pounding with the increased loads at eighty or one hundred miles per hour.

In this connection I am a little surprised that Mr. Churchill, writing from the vicinity of Mr. Gleaves' now celebrated continuous rails, described in our Proceedings a year or two ago, makes no allusion to the question whether such continuous rails are generally practicable. This question was discussed, by Brunel and others, before the Institution of Civil Engineers, early in the "fifties," and shortly after by Elwood Morris and J. Dutton Steele, at the Franklin Institute; and Mr. Moxham's experiments, recently described before the American Street Railway Association, have brought the matter again into public notice. Certainly, if continuous rails can be made available, it would be of the very first importance to the comfort of persons traveling at a rate of eighty or one hundred miles per hour in a railway train.

The rail joint submitted by Mr. Churchill with the present paper, is, I think, generally similar to the one which he described in our Proceedings a year or so ago, and which I then discussed briefly.

Mr. Charles S. Churchill:—I judge from the remarks of Mr. Trautwine in the discussion of my paper on "High Speeds on Railways," etc., that he has overlooked the fact that we are seeking to secure a high average speed over a considerable distance—not a high speed for a few miles alone.

We cannot even secure an average speed of seventy or eighty

miles per hour with an engine capable of hauling a paying train on a straight and level track at one hundred miles per hour, unless grades and curvatures are kept within the limits stated in this paper.

Some of our best railroads that are striving to meet the demands of the traveling public, have for several years been spending enormous sums of money to remove high grades and to reduce curvature on long sections of road to less than four degrees. The value of such changes to operation has already been determined.

Draw-bridges cannot be avoided on many existing roads, and for that reason those very roads are limited in the average speed that can be attained on the sections where such structures are located.

On a new road intended for a very high speed, such as we are discussing, draw-bridges should not be allowed.

As to ties: the number specified is but slightly greater than used on the best roads to-day and the face width of 7 inches for hewed ties is the same. The full width at center of the ties, secured by common railroad specifications for a 7-inch face, is about 10 inches, and the ties will average about 9 inches wide. The use of about 3,000 ties per mile calls for a spacing of 21 inches, center to center, which leaves only 12 inches between ties for ballast. This is found in practice to be quite small enough to secure good results; and 3,000 ties per mile furnish enough support to the rail. It is the rail itself that should be made heavier, and 100 pounds per yard is considerably heavier than used now, excepting on a comparatively few miles of road. I gave this weight rather as a minimum than a maximum for a high-speed railroad.

As to joints: the chief requirement of a rail joint is that it must hold the rails rigidly in place, so that either end cannot move the least fraction of an inch in any direction, except for expansion, and so that the wave or general deflection of the solid rail under traffic may pass unbroken through the joint. Loose and movable rail ends is the cause of all pounding at the joints. With tight rail ends this pounding disappears.

The space $\frac{1}{2}$ inch at the joint of a 60-foot rail is, of course, the maximum. In practice it varies from 0 inch to $\frac{1}{2}$ inch, an aver-

age of $\frac{1}{4}$ inch. This is not a serious matter with good joint fastenings, but is of moment with poor fastenings.

The above is my experience, thus far, with 60-foot rails with square ends. My experience with 60-foot rails with mitre-cut ends indicates that a very great improvement in track is secured by this simple device alone. With good joint-fastening the joints can scarcely be detected while seated in a car.

The rail joint described in the paper has been brought to the attention of the Club once before, as applied to 67-pound rail. A more extended and satisfactory trial of it has led to its adoption by the Norfolk and Western Railroad for use with 85-pound rail.

As to the possibility of securing continuous rail, I do not think it is probable in connection with railroads. It is more possible with street railways, as the traffic and loads are very light compared with railroads, and as the rail is very much protected from effects of temperature by being surrounded by paving.

The experiment made by Mr. Gleaves, near Lynchburg, was on the Lynchburg and Durham Railroad. That road is now one of the leased lines of the Norfolk and Western Railroad, and consequently I am prepared to give the results of that experiment.

I made a personal examination of this experimental track during November, 1891. My report reads as follows:

"Near Gladys is a section of three miles of track put up on the so-called 'Noonan System.' The rails have been riveted together at the joints for the whole distance of three miles, and at each end of the three-mile section is a point switch arranged so as to take up the expansion of the three miles of continuous rail. None of the rails are spiked close to the ties, but there is a little play allowed between the flange of the rail and the under side of the spike head. The ties are completely covered with light earth from the adjacent cuts; in fact, nothing is seen on this section of track excepting the heads of the rails. This track was put up about $1\frac{1}{2}$ years ago. It is now, however, in poor line and surface and it will soon be necessary to remove all the top filling and resurface it, the same as any piece of track. The only advantage secured, therefore, by this system of track is smoothness at the joints, due to the rails being riveted together."

I have a report to-day from the Superintendent of the Durham

Division (the old L. and D. R. R.) of our road, in regard to this piece of track. It is as follows:

"Owing to the ties being buried they are water-sogged, consequently they are very much sap-rotted and probably 50 per cent. of them will have to be renewed during 1893.

"The expansion switch points evidently do not work satisfactorily, as the track is badly kinked, more especially during summer.

"Track also gets out of surface frequently; so you can well imagine what an expensive job it is to resurface it."

From the above it is to be noted:

(1) That ties are quickly destroyed when covered in the manner required in the so-called "Noonan Track."

(2) That expansion of rails cannot be disregarded, even though the track is buried as much as possible, and thus protected from the changes of temperature.

(3) Expansion of a long section of track cannot be carried successfully to one point, even when spikes are kept loose for the purpose.

(4) The track does not remain in the surface, even under comparatively light traffic, as well as ordinary track, and it is very expensive to restore it to the surface.

(5) Therefore the experimental "Noonan Track" is a failure.

I have not taken up the possibility of using other motors than the locomotive.

The earning capacity of a road of any kind is the first item to be considered. The locomotive is the cheapest motor now in existence applicable to railroad service.

If it were expedient to make a change from the use of the locomotive to electricity for a motive power on very busy passenger roads, we have reason to believe that it would have been done before this on such roads as the New York Elevated Railways, where the expense of changing motors would be comparatively light. It seems, however, that after experimenting with electric motors on these elevated railways they are found expensive and unsatisfactory as compared with locomotives.

It is evident, therefore, that at this date there is no motor suitable for the high duty of railroad service that can take the place of the locomotive. As stated in my paper, however, this matter is still open for further invention.

V.

PAINT AS USED ON ENGINEERING CONSTRUCTIONS.

By Edward Hurst Brown, Active Member of the Club.

Read December 17, 1892.

In choosing paint as a topic on which to prepare a paper to read before the Club, it became necessary to confine myself to one special branch of the subject, and even to treat that in the most limited way. If I attempted to cover the whole ground, it would far outrun the time at my disposal, and even then I would fall far short of any exhaustive treatise upon a subject which is so comprehensive that volumes have been written upon it, and still more remain untold. Hence I propose to confine myself, in the main, to a brief discussion of such pigments as are used upon purely engineering constructions for purposes of preservation, leaving out of consideration entirely the whole subject of house painting, in which paint serves more the purpose of beautifying than that of preserving the constructive material. The pigments most used in this latter class of painting are not really those most useful for the engineer, partly because on the rough timber constructions, trestle work, wharves, and the like, expense debars the use of white lead and tinting colors, and partly because those paints which are eminently suitable for wood are by no means the best to use on iron.

A paint, properly speaking, consists of two portions, the pigment and the vehicle or binder.

The *pigment* is a solid substance which is more or less finely ground, so as to be capable (when mixed with the vehicle) of being spread out in a thin layer or coating over the surface to be painted. While the term pigment is sometimes applied to any substance which may be used for painting, whether it be ground finely or not, this is hardly a proper use of the term. A more correct expression would be to define the unground substance as *pigment material.*

The *vehicle* or binder is the liquid in which the pigment is mixed or ground, which serves to spread the pigment over the

surface to be painted and which also holds it to that surface. It may be oil, water, varnish, water glass, or indeed any substance which is capable of performing this function, depending on the work required of it. For ordinary painting, intended to stand the action of the weather, by far the most generally useful vehicle is linseed oil.

Linseed oil possesses the peculiar property of drying by uniting with the oxygen of the air to form a tough, leather-like compound called linoxin. In doing this it loses but little, if any, in weight; whatever weight may have been lost by evaporation, being supplied by the additional weight of the added oxygen. This fact was proved by Mülder, the eminent Dutch chemist and probably the greatest authority on paints, in a series of interesting experiments, in which a certain weighed quantity of linseed oil was flowed upon glass plates of known weight, and as the oil gradually dried it was again weighed and was found not to have varied perceptibly from the original weight, showing that there was practically no loss by evaporation. This drying or oxidizing process seems to take about thirty days to complete, when the oil is spread out in a very thin layer. Of course a coat of linseed oil on a wooden surface will become dry to the touch in much less time than this, but this does not indicate that the process of oxidation is completed.

It has generally been supposed that linseed oil formed a waterproof and water-repelling coating on any surface to which it is applied; but Dr. Charles B. Dudley, the chief chemist of the Pennsylvania Railroad, in a recent series of experiments made by him at Altoona, seems to have proved that this is a misapprehension, and that in reality it is an absorbent of moisture and will transmit air through it. Moreover, in the process of drying it has an oxidizing tendency on the surface upon which it is placed. While these characteristics of linseed oil are rather an advantage than otherwise in the case of paints to be applied to wooden surfaces, since a certain porousness or quality of transmitting air and moisture are necessary to prevent the sap and water from being retained in the wood by the paint and thus causing dry-rot; this very quality of the linseed oil makes it a dangerous vehicle to use in paint intended to be applied to iron construc-

tion, where absolute impenetrability to gases and moisture is essential in order to prevent the metal from being eaten away by rust. Hence it would seem that for a perfect paint for use on iron work we must look for a vehicle which, when dry, is impervious to moisture and gases, and, moreover, one which will be chemically inert and in no way aid the process of rusting. Iron, when heated to redness and plunged into a bath of linseed oil, bakes the oil upon its surface, forming a hard black coating, which is possibly the black oxide of iron, and seems to be a permanent protective coating. This coating is the finish ordinarily employed by makers of grates, andirons and fireplace linings to produce the dull black surface so frequently seen upon their wares, and as used under these conditions, it certainly appears to stand the action of heat and to be at least reasonably free from any tendency to rust. But such a method of treating constructive iron work would be manifestly impossible, not alone from the difficulty of plunging large pieces of red-hot iron work into a liquid bath, but also from the impossibility of preserving the coating from being chipped and broken off by the various processes of riveting, drilling and other handling necessary in fitting and erecting large work. Another very important property of linseed oil, which makes it valuable for paint making, is the fact that it is capable of uniting with various metallic bases (usually in the form of carbonates or oxides) to form a linseed-oil soap.

White lead, or the hydrate-carbonate of lead, the pigment usually used in house-painting, and generally esteemed to be of most value, unites with the oil to form a lead soap, on exposure to the oxygen of the air, thus forming an elastic skin of paint over the surface to which it has been applied. In time, by the gradual action of water, alternating with the heat of the sun, and aided more or less by the sulphur and other gases in the air, particularly in and about large cities, this soap gradually decomposes and the paint begins to chalk or flour off.

Zinc white, or the oxide of zinc, also unites with linseed oil to form a zinc soap, which is harder and more brittle than the lead soap, and has a tendency to contract or pull together when drying and also to peel off in time. It has not the same tendency to chalk and flour that the white lead soap has. Zinc white has,

therefore, valuable pigment properties, but these seem to be most fully developed when this pigment is used in conjunction with white lead, and then to the best advantage when the mixture is used as a final coat over an elastic undercoating of white lead.

On account of the peculiar chemical activity of a white lead and linseed oil paint, which causes its final decay, many experiments have been made looking to the substitution of some chemically inert substance for the more active carbonate of lead, but so far no other white base has been discovered which possesses at the same time the other properties which render white lead valuable, namely, covering and spreading capacity. By covering capacity in a paint is meant the property which any true pigment possesses of covering up or hiding the surface to which it is applied; and by spreading is meant its capacity of being spread out under the brush to cover a considerable surface area. It seems, therefore, probable that if a better paint than lead and oil is desired, experiments will have to be directed rather toward securing an inert vehicle than toward an inert base. So far, for ordinary house painting, nothing has been found to take the place of linseed oil, and all the substitutes offered (and the market is full of them) have disadvantages of one sort or other, which make them undesirable.

Of the inert pigments, lamp black is probably the most valuable. Being almost pure carbon, it is practically unchangeable except by fire. It has a peculiar property of absorbing great quantities of linseed oil and hence of spreading over a large surface.

French ochre, an earth pigment, containing more or less of the hydrated oxide of iron, possesses the property of absorbing a large quantity of oil, and hence has considerable spreading capacity. It also holds very firmly to any wooden surface to which it may be applied, so much so that it is difficult to remove ochre from wood when once it has been painted with it. As this makes a reasonably cheap paint, it is very good to use on rough work where the yellow or yellow-brown color is not objectionable. It has the merit of great durability, and repels water well. It should be ground in raw linseed oil, and if a thinner is required care should be taken that boiled oil is not used. The raw oil

possesses greater penetrative properties and carries the ochre further into the pores of the wood. Ochre has been recommended by some as a primer for use under subsequent coats of white lead. While it has undoubtedly the property of holding fast to the wood itself, it does not hold as well to the white lead coats, which sometimes separate from it in flakes. This could probably be avoided by the addition of a certain proportion of white lead to the ochre for the priming coat.

The various mineral and metallic paints are almost all natural or artificial iron oxides. While these are cheap and useful for painting rough wooden structures, they are sometimes really quite dangerous for application to iron work, because instead of preventing oxidation they are apt to further it. Mineral paints are usually iron oxides, similar in their nature to rust. Rust is a hydrated iron oxide and seems to possess the peculiar faculty of spreading from a center, in some way acting on the adjacent iron to form additional rust; moreover, the artificial metallic paints are frequently made from copperas and from pyrites and are apt to contain sulphuric acid or sulphur in a state readily oxidizable into sulphuric acid, which is another source of danger to an iron surface. On wood, however, they are permanent in color and exceedingly preservative.

Coal tar is much used as a paint for the roughest class of work, both wood and iron, in the latter case especially for cast-iron pipes, smoke-stacks and work to be buried underground. It has the nature both of a resin and an oil. Mülder in a series of experiments found that it continually decreases in weight, losing from two to five per cent. in 87 days. It has also the disadvantage of becoming exceedingly brittle by the action of cold, and softening at 115° Fahrenheit. Asphalt permits of somewhat wider range of temperature, but otherwise exhibits the same peculiarities. Either of these substances, while they last, are probably the most valuable of paints, especially under water, but they are unfortunate in their tendency to flow or crawl on the surface to which they are applied, finally leaving the upper portions almost or quite bare. This is the case even under ground.

Tin or metal roofs are problems requiring most careful consideration on the part of both engineer and architect. Too often a

tin roof is dismissed with the formula, "to have one coat on the under side and two coats on the upper side of best Venetian red," or "metallic paint," as the case may be. There is no mention of the manner of applying the paint, when it should be applied, nor in fact any definite direction. Frequently the tin is allowed to rust before the coat of paint is given, so as to make the paint hold easier, forgetting that the tin is intended to preserve the iron from rust, and when once the tin has gone and the rusting process has commenced, no subsequent coating of paint can prevent it from eating its way through the thin sheet of iron. At the last convention of the Master Painters' Association of New Jersey, this subject of painting tin roofs was most thoroughly discussed, and the general sense of the meeting seemed to be that the best method of painting a tin roof was to carefully remove all traces of oil or grease from the surface of the tin, while it was yet bright, with benzine; then to apply a coat of red lead and linseed oil, or the best quality of metallic paint (Prince's seemed to be favored) and to follow this with one or two coats of graphite paint. The graphite is almost unchangeable by atmospheric action and is remarkably water-proof as well, the rain seeming to slide or slip from its surface.

To determine the proper material to use on structural iron work is perhaps the most important problem that confronts the engineer of construction to-day. In our modern many-storied buildings, this iron work is buried beneath brick and terra cotta, so that it is impossible to observe its condition. Who can say that the causes of rust and decay are less active here than they are when the same material is exposed? What could be more disastrous than the failure of any part of these iron skeletons which support these towering structures? Again, our bridges and the roof trusses in our railroad stations are exposed to constant fumes from the stacks of locomotives beneath them. The smoke is more or less charged with sulphur gases, which, in a moist condition of the atmosphere, are rapidly changed into the actively destructive sulphuric acid. Already the roof trusses in the Broad Street Station have been seriously impaired, and we have had shown to the Club at various times a number of examples of rods and plates from overhead bridges, which have been nearly eaten through by the action of these gases.

In house painting the most important thing to consider is the permanency and durability of the paint itself. Its ease of renewal when it wears out makes it only necessary to calculate the first cost of labor and material and the relative durability of two paints in order to determine their relative economy.

Indeed most house painting is done mainly for beauty, because the color sense is strong in man, and because ever-changing fashion demands renewal of the paint.

In constructive iron work, on the contrary, the condition of the surface under the coating of paint becomes highly important. To the superficial observer the painted surface may appear as perfect as the day it was put on, yet underneath it the iron may be slowly, yet none the less surely, rusting away. In fact it sometimes happens that the paint itself proves an active destructive agency for injuring the iron. This is, as I have said above, specially true of certain of the metallic paints containing sulphur in a form readily oxidizable to sulphuric acid, or of certain of the oxides, such as Venetian red, which are practically rust themselves and give off oxygen to the iron, absorbing more from the outer air to replace that which has been lost. It is said that a similar process takes place during the oxidation of linseed oil, which changes it to linoxin. Were all the oil to unite with the pigment base to form a soap, then none of its oxygen could be given off to rust the iron; but in the case of white lead, according to *Condit*, it is only the water lead (the hydrate) which forms a soap with the oil, while the carbon lead (the carbonate) remains practically unchanged, being held, as it were, in suspension in the oxidized vehicle. Hence a large proportion of the oil, in drying, is free to give up its oxygen to the iron, absorbing more from the air, and thus become an active rust-producing agent. While this theory may not be correct, it is certain that a priming coat of white lead is not a good preservative of iron, nor does it hold well to do it.

Red lead, from the fact that it dries up linseed oil almost entirely by saponification, forming a pure lead soap, and that there is, therefore, none of that oxidation of the oil which takes place in the presence of pigments wholly inert or which only partially combine with it, has long been regarded as the best possible preservative for clean dry iron. But in order to be most

effective, the iron must be perfectly clean and free from any suspicions of rust, and absolutely dry. Red lead should be perfectly pure, and of the best and most careful preparation. That from any well-known corroding house may be depended upon for purity, but not always for quality. It is simply a red oxide of lead. The best type is orange mineral, which is made by roasting white lead. On account of its expense, this is not so frequently used as it would deserve. Red lead proper is made directly from the metal, which is first oxidized to the yellow litharge, and then to the red oxide. This, however, does not give as good a paint as that made from the scrap, settlings and tailings of the white lead works. As red lead saponifies very quickly with linseed oil, it must be used within a few days after being ground, and, moreover, it is rather difficult to work. Hence there is a great temptation to the unscrupulous painter to add some substance, such as whiting, to it in order to make it work freer, as well as to cost less money for material. A very interesting case was recently brought to my attention. On a very large job, a certain painter who had obtained the contract for painting, went to a well-known manufacturer to obtain a price for a paint to be composed in accordance with a sample which he produced, he stating that this sample was furnished him by the contractor for the iron work. On analysis the sample was found to contain fifty per cent. red lead and fifty per cent. whiting, and a price was arranged at which this should be furnished. It was sold to the painter for exactly what it was, with no attempt to deceive him in the case. After the completion of the work, the manufacturer, wondering why such a mixture was specified, sent one of his salesmen to make inquiries in the matter. He succeeded in finding out at the engineer's office that the specification called for "pure red lead." As no benefit could possibly have accrued to the paint manufacturer had he called the attention of the engineer to this violation of the specifications, since he would have succeeded merely in losing a good customer, he decided that wisdom prompted him to say nothing about it. He remembered the words of an astute politician, "Don't talk," and didn't. Had the engineer specified in the beginning that the red lead to be used should be strictly pure, and bear the brand of the manu-

facturer in question, and had he then taken the trouble to notify this manufacturer that his particular brand of red lead was to be used, the pure article would have been sent to the job, and the engineer would have secured for his clients an honest instead of a rascally job of painting.

Before painting iron work it is very essential that the iron itself should be absolutely free from rust. Rust has the peculiar property of spreading and extending from a center, if there be the slightest chance to do so. Hence, a small amount of rust on the iron may grow under the surface of the paint, especially if it be true, as Dr. Dudley asserts, that linseed oil is permeable by air and moisture, and in time the paint will be flaked off by the rust underneath, thus gradually exposing the bare surface of the iron to the action of its destroying agents, oxygen in the presence of water. It is necessary to remove all the scale possible from wrought iron by means of stiff wire brushes, and then to remove the rust by a pickle of very dilute acid, which must afterward be thoroughly washed off before the paint is applied. The surface of the iron should be dry and at least moderately warm before it is primed. Hence, the specifications usually call for the priming with red lead, to be done by the iron manufacturer, before its delivery to the job. It has been suggested that rust may be quickly and thoroughly removed from iron by coal oil. This should afterward be washed from the surface with benzine, which should be allowed to evaporate before painting, otherwise the coal oil, being practically non-drying, would inevitably cause the paint to peel from the metal. Red lead, to secure the best results, should be thoroughly incorporated with the oil in a mill, and not merely stirred in by hand. While the use of red lead appears to be very general, its success depends so very much upon the care which the workmen take in preparing the surface to be painted, that it seems desirable that some paint should be found to take its place, which may be applied either to a hot or cold surface, and which should be ground in a vehicle rendered practically inert, so that it would not in itself tend to promote rusting already begun, or to start it on a surface where it had not already commenced. This vehicle, if it be possible, should be one which would be absolutely impervious to gases or moisture.

With this idea, a well-known firm of paint manufacturers of this city, months ago began a series of investigations into the subject, and, after many experiments, produced a paint which they have called "Anti-Rust." So well satisfied have they been with the tests, that they have applied it to the corrugated iron roof and sides of a new acid chamber building, just completed, in which the iron would be subjected to the peculiarly trying action of the fumes of sulphuric acid. As a sample of the severe tests to which a paint is put by a conscientious manufacturer before the material is offered to the public, iron pipes were painted with this material, and were exposed for over a week to the heat from steam passing through them at 100 pounds pressure. This was done in the boiler-house, where they were exposed to the fumes from the burning coal. They were then placed in a freezing mixture of ice and salt, where they were kept for twenty-four hours. The pipes show for themselves how well they stood the test. Ordinary paint, mixed with linseed oil, under the usual conditions, would undoubtedly have peeled, blistered or softened, when subjected to either of these tests. In the factory there are numerous steam pipes, running from one building to the other for the purpose of conveying steam for heat or power. The "Anti-Rust" has also been tried upon these, and exhibits no tendency whatever to blister, and it appears to be baked upon the surface. So far as the most careful experiments would seem to indicate, the vehicle, when dry, forms an absolutely impervious coating to gases and moisture. It has been prepared with three different pigment bases: a brown oxide of iron, which is not highly recommended, as it is not the highest form of oxide, and might, perhaps, be subject to change; the bright red ferric oxide, 98 per cent. pure, which some of the most eminent German authorities of the present day believe to be the most suitable pigment for painting iron, since it is practically unchangeable, and being itself iron, there can be no electric action between this and the metallic surface to which it is applied. The third pigment, and, in the judgment of Dr. Dudley, the best, is black, which seems to be chemically and electrically inert. Using this paint as an outer covering over a priming coat of pure red lead, would probably give the best protection to iron, combining thus the advantages of both paint materials.

One very important point in painting engineering constructions is the specification under which the work is done; too much care cannot be given to its proper preparation; the engineer should not only consider the scientific names of things, but what those things may mean in the trade: for example, he may specify iron oxide paint, red or brown, expecting to get the pure oxide. In the trade such a specification would indicate merely that he desired a paint material *tinted* red or brown with iron oxide and would not show at all that he desired a pure pigment, unless it was so specifically stated. Unless he be thoroughly familiar with all the technical terms and trade designations, his best plan would be to consult a manufacturer on whose judgment and honesty he can rely, and by his aid draw up a suitable specification for the work on hand. It seems to me an entirely false view of the matter which induces some engineers and architects to refrain from specifying definite brands or makes of materials. When they know these to be good and feel certain that by specifying a definite brand they can insure for their client the employment of good and pure material, it then becomes their duty to do so.

The extent to which adulteration can be carried is hardly suspected outside of the trade. Enormous quantities of finely ground white materials, mixed with linseed oil, or oftener with an oil largely " doped " with some cheap and nasty rosin oil, are sold every year labeled as pure white lead, although in many cases they have not a particle of white lead in them, and seldom more than 25 per cent. They consist largely of barytes (sulphate of barium) which, being almost as heavy as white lead, escapes detection readily, whiting, gypsum, etc., with enough zinc white to give a certain amount of pigment property. All these adulterants are absolutely without covering power or pigment value. Spread upon a board, when ground alone in oil, they absolutely fail to hide its surface, and possess little or no power to withstand the action of the weather.

There is a prejudice on the part of many against using a ready-mixed or prepared paint, and this is largely due to the extent to which these adulterants have been used in the cheap ready-mixed paints and tinted leads with which the market has been

flooded. But if a man does not look for more than a dollar's worth for a dollar, he can find good, honest materials in ready-mixed paints. Why then, in this age of machinery, is it not logical to mix our paints in large quantities by proper machines, rather than to trust to the rule-of-thumb methods of the average mechanic, who pours a little lead into a pot and adds a quantity of oil by guess, stirring the two about with a stick until he imagines he has got it about right. It seems to me to be most logical to specify machine-mixed paints of the very best obtainable brand, taking care, however, that they be manufactured by some house with whom pure means pure, inside the cans as well as on the labels outside. There are such manufacturers whose reputation for honesty is too great and too valuable to trifle with it by branding any but honest goods with their name. Such firms honestly deserve patronage, and well deserve mention in the specifications of architects and engineers.

Would it not be well to pay more attention to the paint problem than engineers have been in the habit of doing. Too often the entire matter has been dismissed from the mind when the words "two coats of mineral paint," or "three coats of red lead and linseed oil," have been written in the specification. Does not the very life of the building or the bridge depend often on the outer skin of paint which should serve to protect it from the ravages of the elements, or the destructive action of deleterious gases? It pays to experiment in order to determine the very best paint to suit given conditions; or should experiment on your part be impossible, then seek expert advice on the subject from those who have made paint, its manufacture and its wearing qualities, the study of their lives. It pays to spend extra dollars in the beginning to save ten times the amount in the end. The cost of the material is but a small part of the cost of painting. Labor is by far the larger portion. It is poor economy to use any but the best material obtainable. When iron work is concealed from sight, buried behind brick-walls or under superincumbent masses of masonry, the rusting away of a bolt or rivet may cause the collapse of the entire structure, and bring death and destruction in its wake; the engineer should not haggle over a fraction of a cent in the price of a pound of pigment, he

should seek the most enduring and insist that it be used, even though the first cost of the structure be increased thereby. The increase at the utmost can be but a small one, a fraction of one per cent. of the total cost of the work—yet that small added increment may increase the durability of the work an hundred-fold, and may save innocent lives and valuable property from destruction.

VI.

THE DEVELOPMENT OF THE INJECTOR.

By Strickland L. Kneass, Active Member of the Club.

Read October 1, 1892.

It would be necessary to search among the earliest discoveries of which we have record to determine the first inventor who sought to utilize the energy of a discharging liquid or gaseous jet; even though there may be an apparent similarity between the action of the Injector and that of the earlier inventions, the difference lies in principle as well as in essential detail; ejectors—as they are termed—can operate with any gas or liquid in connection with any other gas or liquid, while the action of an injector depends upon the expansion and condensation of gaseous fluids, acting within clearly defined limits. Technically, an injector may be defined as an apparatus in which a gaseous jet impinges, and is condensed by a fluid mass whose final kinetic energy exceeds the potential energy it would have under the initial pressure of the motive jet. This requires in addition to the use of condensible gases the existence of certain well-established relations between the areas of the discharging and the receiving nozzles, that will serve for a clear distinction between the two types of apparatus. An injector requires under ordinary practical conditions, the receiving or delivery tube to have a smaller cross-section than that of the motive jet; in an ejector, the delivery tube must be the larger.

In the year 1858, Henry Jacques Giffard, an eminent French engineer, brought to the notice of the scientific world a new apparatus for supplying steam boilers with feed water, which attracted the attention of scientific as well as of practical men and occasioned much discussion in engineering circles. At that time scientific knowledge was not so generally distributed as it is at present, and therefore the unpretentious little device of Giffard, appearing more like a collection of pipe fittings and flanges than aught else, seemed to many of those who saw it in operation, to set at defiance all the well-known laws of mechanics, and to prove the possibility of perpetual motion.

Giffard, however, had so thoroughly mastered the principle of his invention, and enjoyed so clear an appreciation of the possibility of its development, that he not only fully explained the principle underlying its action, but also clearly described in his patent specification many improvements that have since been added. In 1860 he published a small brochure, entitled, "A Theoretical and Practical Paper on the Patented Self-Acting Injector," in which he says, "Of all the necessary accessories of a steam engine, perhaps the most important is that used for feeding water to the boiler; upon its proper working depends not only the regular working of the engine, but the safety, the very existence of those who approach the boiler; . . . . nevertheless, by a kind of fatality, the apparatus employed up to the present time for feeding, is, of all others, that which leaves most to be desired."

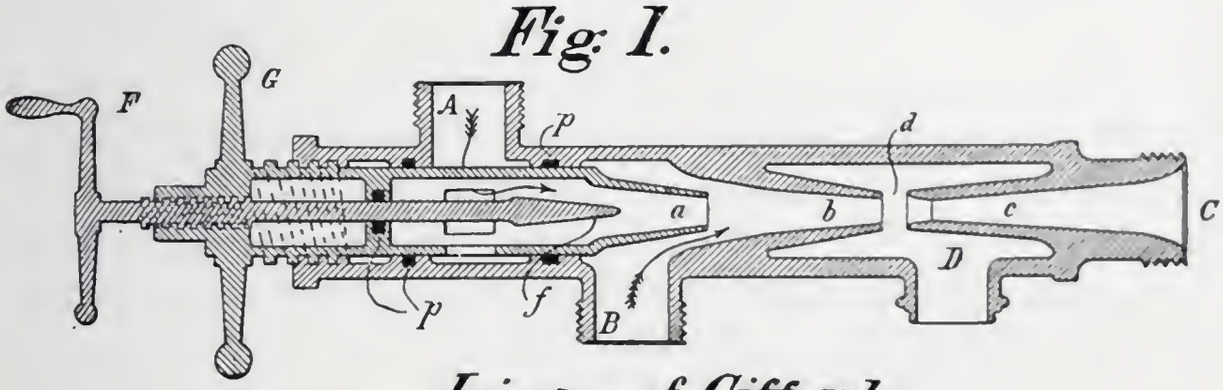
After reviewing the disadvantages of the various methods then in use, he continues: "It is important to create a new method, free from the imperfections and inconveniences pointed out," and modestly adds, "such is, it appears to me, the result obtained by the apparatus to which I have given the name of *Injector* because it produces a veritable continuous injection. Its mode of action, extraordinary in appearance, contrary to that which we are in the habit of seeing or supposing, is explained by the simplest laws of mechanics, and has been foreseen and calculated in advance." It is true that the inventor had set forth the theory of the injector substantially as stated in the pamphlet from which quotation has been made, as early as 1850, and before any experimental injector had been constructed.

He thus describes his invention in his provisional specification (English patent, July 23, 1858): "A peculiar construction and arrangement of apparatus for supplying feed water or other liquid to steam or other boilers, and for raising and forcing fluids generally. . . . The invention consists of a steam or injection pipe. which receives the steam from the boiler and directs it in a continuous jet into a small passage, the lower end of which is expanded sufficiently to admit of the entrance of a stream of water, which, surrounding the steam jet pipe, forms an annular jet of water with the steam in the center. . . . The water has an

impulsive force imparted to it by the steam jet, and simultaneously receives a considerable amount of heat therefrom before it enters the boiler. On issuing from the narrow passage above referred to, the jet of water enters the second passage, which is expanded at its upper end, . . . such expansion being gradual . . . and serves to diminish without shock the impetus which has been imparted to the fluid." (The American patent is dated April 24, 1860, and contains the same description.)

As originally constructed, the mechanical details of the injector were far from perfect, and this doubtless delayed somewhat its general adoption as boiler feeder; a serious objection, also, was the great care required to lift the feed water, especially when the suction pipe was very hot; a still more serious trouble with the original Giffard injector, and one characteristic of this type, was the necessity for frequent adjustment by hand of the positions of the tubes for any change in the pressure of the steam or of the feed water. Before explaining the means by which this was obviated, it will be necessary to describe briefly the different parts of the Injector, their functions and the method of operation. The instrument consists, essentially, of three parts: a steam nozzle (*a*) for guiding and forming the steam jet; a combining tube (*b*), that limits the entrance area for the water, and in which

Fig. I.



Injector of Giffard.

the steam impinges the feed water and is condensed; and a delivery tube (*c*), where the velocity of the combined jet is gradually reduced so that it can enter the boiler without loss of energy; a short overflow space (*d*) separates the combining from the delivery tube.

The injector is operated as follows:—The spindle *f*, is screwed

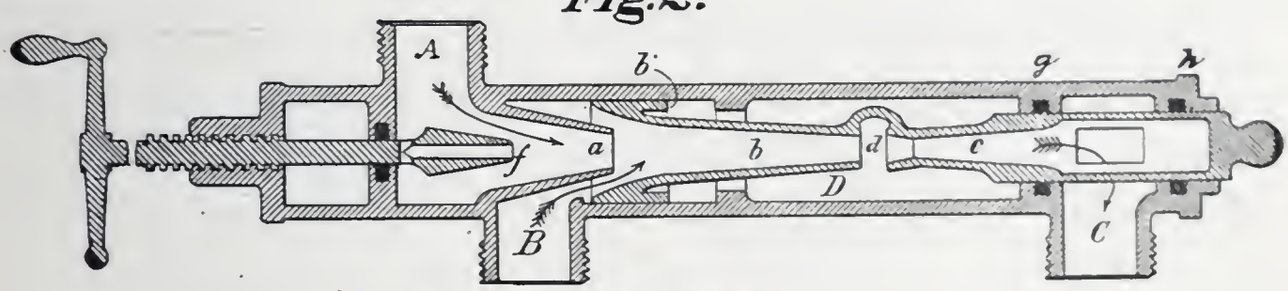
down until the effective area of the steam nozzle *a* is approximately one-quarter that of the lower end of the combining tube; steam is then admitted through *A*, and discharging with great velocity through *b* finds outlet by the overflow space *d* to the waste pipe *D*; a partial vacuum is formed in the suction pipe *B*, and when the feed water rises and flows from *D*, the spindle is drawn back, and the impulse received from the discharging steam drives the water through the contracted section of the delivery tube and the branch *C* into the boiler. The handles *F* and *G* are used for adjusting the entrance areas of the water and the steam.

Assuming the correct relations and proportions to exist between the parts, a steam jet after condensation will enter a boiler against its own initial pressure, carrying with it many times its weight of water. All other conditions being the same, reduce the boiler pressure, and the steam will not have the power to force the same quantity of water through the delivery tube, and the surplus will therefore spill out through the aperture between the tubes, and issue from the waste pipe; on the other hand, if the pressure be increased, more steam will be discharged, and there will be an insufficient supply of water to condense it during the passage of the jet through the combining tube; consequently a contraction will occur while the jet is crossing the overflow space, and an indraft of air will result. Therefore, to produce the most efficient action in the injector, the condition of the jet during its passage across the overflow must be neutral at all steam pressures, and the vacuum in the combining tube constant, and as high as possible. There are only two practical ways of accomplishing this and altering the supply of water to suit the supply of steam. First, varying the area through which the feed water is admitted, and second, changing the pressure under which the water flows. Giffard appreciated this, and manufactured his injector with hand adjustments for both water and steam, so that the required proportions could be obtained under all conditions. But the problem was to make this adjustment automatic. In Giffard's patent two methods are described by which this could be done: by permitting a sliding steam nozzle to be moved away from or toward the combining

tube by the pressure of the steam, and balanced by an exterior spring; but this evidently was not practicable. The second method was to increase the pressure of the feed water flowing to the combining tube, by sub-dividing the steam jet, using a small part for lifting the feed water and delivering it under pressure to the second and larger nozzle; this was clearly described in his specification, and also various modifications that may be permitted by the use of internal or external water or steam jets; it is singular that this line of discovery was not developed by other inventors until many years later.

The simplest and best device would be one that kept the condition of the jet during its passage across the overflow space nearest to its normal condition, and any change in the condition of the jet would tend to restore the changed relations. This was very simply done by William Sellers, in August, 1865, by placing the overflow aperture *d* between the combining and delivery

Fig. 2.



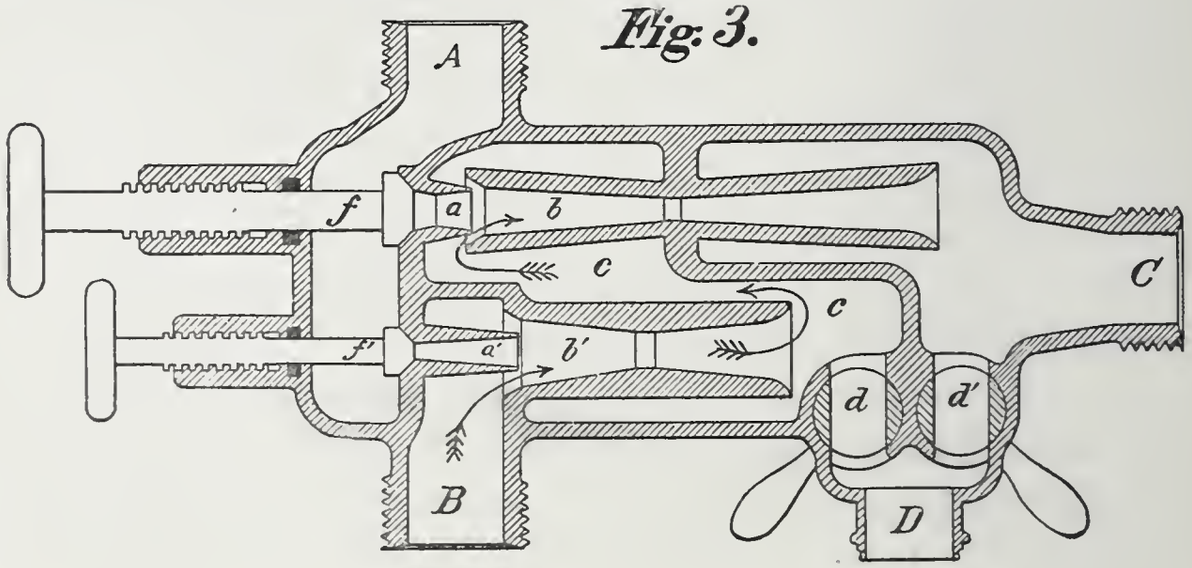
Self-adjusting Injector.

tubes, in a closed chamber *D*, formed between the piston head of the movable combining tube *b* and the lower wall of the casing; as the overflow chamber had no outlet to the air, it was necessary to place a relief cock (not shown on figure) beyond the delivery tube in order to start the jet. The combining and delivery tubes *b* and *c*, were rigidly connected and moved freely toward and from the steam nozzle, as they were balanced with regard to the boiler pressure, by passing through stuffing boxes *g* and *h*. This formed a perfectly self-regulating injector, for an excess of water supply would cause the closed overflow chamber *D* to fill, exerting an unbalanced upward pressure upon the combining tube until the wasting ceased and the normal condition re-established; a rise in the steam pressure would produce a partial vacuum

below the combining tube, and moving it downward until the water space was enlarged sufficiently to admit the required amount of water. The capacity of the injector could be diminished by inserting a taper spindle *f* in the steam nozzle, and the combining tube would automatically adjust its position to admit sufficient water to condense the reduced weight of steam discharged. An increase in the height through which the feed water had to be lifted, would be immediately counteracted by a downward movement of the combining tube, and the same quantity of water would flow into the injector as under more favored conditions. This formed an instrument that would operate with the maximum efficiency under a very wide range of steam pressures. Modified only in construction for simplicity and for convenience of operation, this injector is largely used at the present time in locomotive service, where the pressure of the steam is subject to material variation.

The other method of automatic adjustment by varying the feed pressure, although not introduced in direct chronological order, will, for convenience, be described in this connection. In 1876, two American patents bearing upon this principle were applied for, one by Ernest Körting, of Hanover, Prussia, and the other by John S. Hancock, of Boston; each showed an Injector consisting of two distinct jet apparatus in which the delivery tube of the first or lifting jet discharged into the combining tube of the second set. Steam could be admitted to the nozzles separately, in order that the lifting jet might perform its functions in advance of the forcing set, as shown in Fig. 3.

Fig. 3.



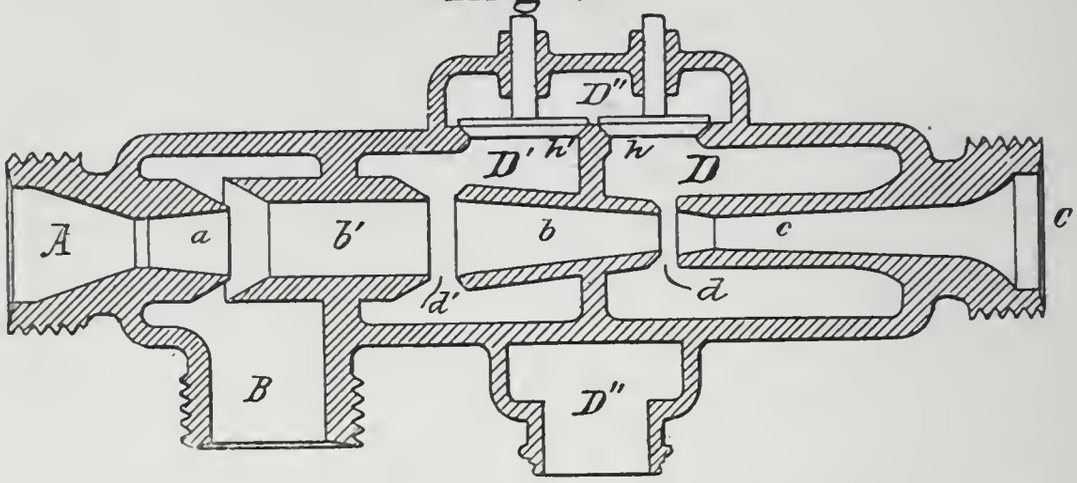
The operation was as follows: Steam discharging through the lifting steam nozzle a', entered and completely filled its delivery and combining tube b', entrained the air contained in the suction pipe and discharged through an open cock d between the two sets of tubes; when the water rose, the outlet was closed, and the water compelled to pass through the forcing combining tube b of the second set, and found vent through the final waste cock; the forcing steam nozzle a was then gradually opened, and the second jet established, entering the boiler as soon as final overflow cock d' closed; the spindles f and f' are provided so that steam may be admitted to the two nozzles separately, and cocks or valves beyond the delivery tube are substituted for the usual starting overflow placed between the combining and delivery tubes.

When the correct proportions of the tubes and nozzles are closely followed, this double apparatus is a very perfect self-regulating injector. It depends upon the principle of varying the pressure of the feed water with the steam pressure, and this function is performed by the first set of tubes, which increases the pressure in the intermediate chamber c as the steam pressure rises. Numerous special devices were afterward added by later patentees to facilitate the opening and closing of the steam and waste valves by the motion of one starting lever, and it is at present one of the most convenient and universally applied Injectors.

Turning now to the development of the other typical division, the Single Jet Apparatus, we find numerous improvements in the construction of the injector made by various inventors. Robinson and Gresham, in 1864, adopted special ways of moving the combining tube by hand, and discovered that the overflow space between the tubes could be considerably lengthened without materially affecting the efficiency of the instrument. Körting, Mack, Little, Sellers, Friedman, Bancroft, and others, assisted with various special devices to improve the efficiency and to increase the range of capacities and the temperature of feed water that could be used. In 1879, Hamer, Metcalf and Davis introduced the exhaust injector, but as this involves no new principle, but only a difference in the proportions of the parts, no further

explanation need be given. In 1881, John Loftus, of Albany, N. Y., made the discovery that a live steam injector could be made re-starting, so that if the continuity of the jet were disturbed, it would be instantly and automatically re-established.

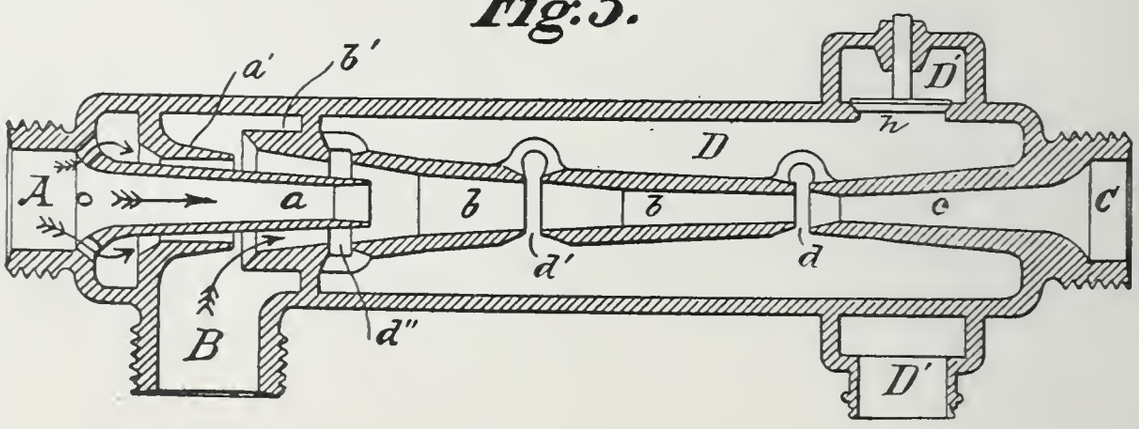
Fig. 4.



This was effected by introducing a short suction or draft tube b' between the steam nozzle a and the combining tube b'; the overflow d', opened into a separate chamber D', closed against admission of the exterior air by means of the check valve. The upper opening d' was made larger than the effective area of the steam nozzle, so that a free discharge of steam could be obtained, and a partial vacuum would be formed in the suction pipe B. This type represents all the single jet automatic injectors of the present day, but as they all have a fixed opening between the steam nozzle and combining tube, the self-adjusting feature is lacking.

In 1885, J. S. Bancroft, of William Sellers & Co., patented a device that obviated this fault entirely; modifying the form of the double jet injector by the addition of overflow openings to both sets, all communicating with one overflow chamber, an apparatus was devised that combined all the self-adjusting advan-

Fig. 5.



tages of the double jet with the re-starting feature of the Loftus Injector.

Continued experiments, by the same firm, developed a simpler device, invented by the writer in 1887, in which the lifting and forcing tubes are in the same axial line. This injector is shown in Fig. 5, where *A*, *B*, *C*, refer, as before, to the steam, water and boiler connections; the steam nozzle is divided into a lifting nozzle *a′*, and a forcing nozzle *a*, differing from the Double Jet Injector already described, in requiring no valves for separate steam admission, as the large additional overflows *d″*, *d′*, in the combining tube *b b* permit such free discharge for the steam that a partial vacuum is formed in the suction pipe *B*, under all conditions of steam pressure. The arrangement of the nozzles and the common overflow chamber produce a very complete self-regulating action, and obviate the necessity of any hand manipulation for variation in steam pressure.

These devices bring the development of the invention of Giffard up to the present day, and show a marked advance from the original apparatus as manufactured by H. Flaud, in 1860. Mention has been made only of those improvements that seem to mark steps in development, and for that reason many well-known injectors are not described, as they are simply modifications of the types shown. It is true that many of the improvements here referred to may seem to be merely matters of detail, yet by these modifications the objections urged against the Injector as a boiler feeder have been overcome, and it is now a most necessary adjunct of the steam engine.

It need hardly be said that the injector is the most popular method of boiler feeding extant. There have been more than 500,000 manufactured in the United States for various kinds of service, and there is now scarcely a locomotive in the world that is not equipped with one or two instruments. Compact, reliable, economical, it still deserves the high encomium bestowed upon it by the eminent French writer, M. Ch. Combes, Inspector-General and Director, L'Ecole des Mines: "It is, without doubt, the best of all devices hitherto used for feeding boilers, and the best that can be employed, as it is most ingenious and simple."

NOTE.—The paper was illustrated by sectional models illustrating the different steps in the development of the Injector, loaned by Messrs. Wm. Sellers & Co., Incorporated, and L. Schutte & Co.

JOSEPH N. DU BARRY.

The life and work of Mr. Du Barry seem to be worthy of especial notice by the Engineers' Club of the City of his residence and home.

When he began his engineering work, the West Point Military Academy was almost the only technical school of note in the country, and active service in the camp and on construction was the only easily obtained preparation for the civil engineer, just as the apprenticeship in the shops of Winans, Baldwin, Norris and others was the only school for the mechanical engineer.

The mining engineer was just beginning to be recognized in this country as a distinct member of the profession, and the modern electrical engineer had not yet appeared.

His elders and predecessors were such men as Edward Miller, J. Edgar Thomson and James Lowry, whose work should always be remembered by the more technical, later members of the profession; and it is therefore as a link joining and intimately connected with two almost distinct eras in the history of American engineering, that we now appropriately note the life-work of Joseph N. Du Barry, who was born at Bordentown, N. J., November 30, 1830, and died in Philadelphia on December 17, 1892.

It was natural, and, as it proved, not unfitting, that he should have been named after two renowned members of the house of Bonaparte; for his father, a surgeon in the United States Navy, was for some time the medical attendant of the exiled Joseph Bonaparte, ex-King of Spain, Count de Survilliers.

As it is his professional career as an engineer that it is most proper to record in the Proceedings of this Club, the retrospection of this life of sixty-two years of untiring energy and unceasing labor, affording as it does nearly a half-century of unremitting zeal for and activity in his profession, presents a picture at once charming, bold and instructive, and adds another medallion to the line of this Club's honored dead, which already contains Robinson, Lorenz, Kneass, Worrall and Trautwine.

To those of us, not contemporaries, who read the pages of this

life as history, it seems almost incredible that in forty-five years of professional work so much could have been accomplished; and yet its result is the natural outcome of a national trait—industry. Mr. Du Barry was successful, fertile of resources, fearless in his undertakings; but he merited the distinguished position he occupied at the time of his death chiefly because he was never idle.

Entering the service of a great railroad in 1847, as a rodman, his firmness of purpose, faithfulness in discharging his duties and unquestioned integrity won for him, step by step, the distinguished position of a Vice-President of the Pennsylvania Railroad Company, which he occupied from 1882 to the time of his death. In addition to having direct supervision over all construction work, he had under his direction, since 1887, the treasury and insurance departments, and the care of all the financial interests of the many affiliated corporations of that railroad.

This last decade of his most engrossing and confining work practically comprises the period of his membership in this Club, to which he was elected June 18, 1881; and for this reason, more than any other, was his presence seldom noticed at our meetings, and our Proceedings were deprived of the valued contributions his ripe experience could have given us.

Mr. Du Barry's accomplishments and career are too well known, however, to need the embellishment of any pen; for, as was beautifully stated by the officiating clergyman at his funeral, his monuments are in the mountains of Pennsylvania, where he was early called upon in connection with the preliminary surveys and location of the Pennsylvania Railroad between Altoona and Pittsburgh, to develop that pluck and steadfastness of purpose which characterized the man throughout his life.

After three years in such a rugged but instructive practical school, he was made Assistant Engineer of Construction in 1850, and with only a brief interval of five years from 1853 to 1858, first as Assistant Engineer of the North Pennsylvania Railroad, and afterwards as Principal Assistant Engineer of the South Western Branch of the Pacific Railroad of Missouri, Mr. Du Barry's professional life is honorably recorded in the archives of the Pennsylvania Railroad.

As Superintendent and Engineer of the Western Division of the Pittsburgh, Fort Wayne & Chicago, until 1861; General Superintendent of the Northern Central, and afterwards, in 1867, as its Vice-President, he had ample opportunity during the exciting period of the Civil War to exhibit his splendid executive abilities, and it is but simple truth to state he discharged his exacting and often perilous duties with entire satisfaction to his company and with abundant honor to the Nation at large.

As was well expressed by one of his assistants in the operation of the road in those days, in a recent letter to a member of your committee: "By day and by night Mr. Du Barry gave his personal attention to the transportation of troops, provisions, munitions of war and the vast number of civilians moving in and out of Washington City, the base of all army operations. Box, stock, gondola and even coal cars had to be called into use whenever large or rapid movements were to be made. No call was ever made upon him by the Governments—State and National—to which he did not instantly respond; no emergency arose that he was not equal to. He had, and ever retained, the confidence of the highest official of the land, who frequently sought him for conference. One instance of his stirring zeal was in connection with the movement of the train containing ammunition to be hurried forward to Hagerstown, so as to enable the renewal of the battle of Antietam by McClellan.

"Among the great young men of that day who aided in preserving the principles of this Government, the unity of the Republic, and the development of the material interests of the country, he was not the least."

Among the most important and substantial of his engineering accomplishments were the rebuilding of some twenty bridges on what is now the Frederick Division of the Pennsylvania Railroad, including the long Columbia Bridge, which had been destroyed to hamper the advance of the Confederate forces into Pennsylvania at the time of the Gettysburg campaign. The construction of the difficult Baltimore & Potomac tunnel under the city of Baltimore, while built in the interest of the Pennsylvania Railroad, also came under his supervision whilst Vice-President of the Northern Central.

On his election, in February, 1875, to the position of Assistant to the President of the Pennsylvania Railroad Company, his skill and experience were mainly directed in the channel of supervising the construction of all new engineering work; and how faithfully and conscientiously this office was discharged was made manifest by his being left in charge of the same department until the time of his death, when he was a director in ninety-eight different corporations in which the Pennsylvania Railroad was monetarily interested. Since 1882 his attention was also directed to the revision of grades on the Western Pennsylvania Railroad and to the construction of the Schuylkill Valley Railroad, one of the longest and most difficult branches and now an important Division of the system. He also built the Germantown & Chestnut Hill road, the Trenton cut-off, and the Cambria & Clearfield Railroad, but recently completed, and destined to be an important feeder of bituminous coal tonnage to the main line.

Besides holding a membership in this Club, Mr. Du Barry was a member of the American Society of Civil Engineers, and the Institution of Civil Engineers, London, and was enrolled in many other kindred societies and clubs of this city and country.

His sudden death, on December 17, while a great shock to his family, his associates and the community at large, came with comparative ease and absence of pain, and even while his thoughts were turned to the business of the great corporation he served so long and well.

If there be any who recall his faults, all will acknowledge that they were open and insignificant. Like his heart, "they were worn on his sleeve," and no one who came frequently in contact with his big, generous nature, his rugged integrity and scrupulous conscientiousness, could fail to appreciate his honesty of purpose, manly simplicity and strong personality. His genial temperament also rendered him accessible to young and old, and endeared him to many who only knew him as the honest man, the sincere friend and the capable engineer.

Such was the life-work of Mr. Joseph N. Du Barry, and as an example, commends itself to the young engineer, and should bear a consolation to his beloved wife and children, who knew

him in the home circle as a loving husband and affectionate father.

The four other members whose deaths occurred during 1892 were: Frank E. Richardson, Active Member, elected November 21, 1891, died March, 1892.

Edward Nichols, Active Member, elected December 1, 1883, died January 7, 1892.

H. W. Clarke, Active Member, elected April 7, 1883, died February 23, 1892.

Joseph Powell, Jr., Active Member, elected April 2, 1887, died December, 1892.

NOTES AND COMMUNICATIONS.

THE HEATING OF DWELLINGS FROM A SANITARY POINT OF VIEW.

By George T. Gwilliam.

Read December 3, 1892.

The difference in the cost of steam or hot water apparatus, when compared with hot air furnaces, will make the latter the most popular method of heating dwellings for some time to come. The heater in common use is of the "portable" type, made up of a cast-iron fire-box, with a system of wrought or sheet iron drums and tubes, the whole covered with a sheet iron jacket, from the top of which the heat pipes diverge. To supply moisture to the heated air a cast-iron water-box is located at some point of the heater to suit the fancy or convenience of the workman; the box will hold from one to three gallons, and seldom contains water, usually mud and rust; the heat pipes are seldom tight and rarely covered. The cracks and crevices around the cellar windows and the foundations of the house, supply the heater with fresh air; it collects, in its passage across the cellar, coal dust, ashes and the different odors commonly found in cellars; the gases from the leaky heater joints are added, then it is delivered throughout the house at varying temperatures, from 60 degrees in very cold weather to 140 degrees when the weather moderates.

In theory the question of heating and ventilating should go hand-in-hand; the practice is, however, to heat only. While it is next to impossible to get a heater that is perfectly tight, a good one can be selected; one with a minimum number of joints, and it should be large enough to heat the volume of air required without forcing. The fire-box of a heater should not be allowed to get red-hot. The pipes conducting the heat should be run direct, avoiding abrupt turns and horizontal runs. The jacket of the heater and the heat-pipes should be covered with some non-conductor. The water-pan, properly placed, should be connected with a tank having a ball-cock, so the water supply will be constant.

All rooms should have some means of ventilation, and when no provision has been made to that end, good results can often be obtained by simply adjusting the window-sash.

Since the introduction of laws regulating house drainage and plumbing in this city, the character of the work has changed greatly for the better; and if similar laws were passed regulating heating systems, much sickness arising from breathing impure air and gases from defective heaters would be avoided.

ABSTRACT OF MINUTES OF THE CLUB.

From October to December, 1892, *inclusive.*

Business Meeting, October 1, 1892.—President James Christie in the chair; 39 members and visitors present.

The Tellers reported the election of the following gentlemen to active membership: Messrs. Pierre Giron, William L. Austin, J. S. Robeson, George H. Paine, Daniel W. Pedrick, Charles S. Schwarz, W. G. Coughlin, Paul L. Wolfel, William C. H. Slagle, George F. D. Trask and Silas G. Comfort.

The resignation of Mr. Edwin S. Cramp was presented and accepted.

Mr. Strickland L. Kneass read a paper on "The History and Development of the Injector," giving a detailed description of the Giffard Injector as originally constructed, and the improvements devised to overcome the objections urged against it. (Published in this number.)

Mr. Carl G. Barth gave an interesting blackboard discussion of the Distribution of Pressure in Bearings, maintaining that the center of pressure in an ordinary step bearing should be taken at one-half the radius, instead of two-thirds, as is usual. (Published in this number.)

Regular Meeting, October 15, 1892.—President James Christie in the chair; 26 members and visitors present.

Mr. John C. Trautwine, Jr., presented notes on the Distribution of Pressure in Masonry Joints, illustrated with sketches on the blackboard, showing that the true significance of the "middle third" of the joint, and of the "tension" which is said to occur when that limit is exceeded, lies in the fact that masonry joints are practically incapable of resisting tension, so that when in such a joint the resultant of all the pressures falls outside the middle third, the portion of the joint which, if capable of tension, would be called upon to exert it, is simply idle, and the entire pressure is concentrated upon the remainder of the joint, the width of which is three times the distance from the resultant to the nearest edge. Owing to this, the maximum unit pressure in such joints increases very rapidly after the middle third is exceeded; whereas, in a surface capable of resisting tension (such as a cross-section of an iron bar) the maximum unit pressure increases uniformly, however far from the center of the section the resultant may fall.

Mr. Wilfred Lewis gave an account of his "Investigation of the Strength of Gear Teeth," beginning with a reference to the elementary character of the problem and the great diversity of rules adopted by many recognized authorities, and showing that although the form of a tooth had long been known to be an important factor in the determination of its strength, none of the rules in common use took account of the strength as affected by the number of teeth in the wheel or pinion. (Published in this number.)

Business Meeting, November 5, 1892.—President James Christie in the chair; 32 members and visitors present.

The resignations of Messrs. Thomas H. Graham and C. A. Preston were presented and accepted.

The Tellers reported the election of Messrs. Joseph R. Clausen, Robert C. Matlack, Jr., S. Godfrey Griffith, Gordon S. Stayman, George L. Martin and William D. Beatty to Active Membership, and of Mr. Thomas W. Jenks to Associate Membership.

Dr. Henry Leffmann read a paper on "The Water Supply of Philadelphia." The location and treatment of a water supply, he said, was an engineering rather than a chemical problem. Chemical analysis may throw considerable light upon the sources of supply, such as wells and springs, and may be of much benefit in studying the effects of aëration, storage, filtration and other incidents to which the matter may be subjected, but a careful inspection of the territory covered by the streams from which the water is taken is always necessary in determining the value of a river or other surface water. A survey will often reveal more dangers than an analysis. Further, streams ramifying over a wide water-shed are subject to such variations that nothing but a constant supervision could keep account of the changing chemical and bacteriological conditions.

Considerable discussion followed the reading of this valuable [illegible] greater part of which is given elsewhere in this number.

Regular Meeting, November 19, 1892.—President James Christie in the chair; 30 members and visitors present.

Professor Spangler called the attention of the meeting to changes which the Revision Committee of the Board of Directors had suggested for the New Constitution and By-Laws for the Club.

Most of the changes were in wording and arrangement, the few radical ones being as follows:

The appointment of the Secretary by the Board of Directors, instead of his election by the Club.

Making the number of votes necessary to reject a candidate for Active Membership five per cent. of the legal votes cast, and in the case of Honorary Members three per cent. of the legal votes cast.

Increasing the annual dues of Resident Members and Associates to $15.00.

Limiting the Honorary Membership to one per cent. of the Active Membership, and time for election of Honorary Members to the Annual Meeting.

These matters were then informally discussed by several of the members present.

Mr. John Birkinbine approved the proposed recommendations, but suggested that the proportion of adverse votes necessary to reject an Honorary Member might well be increased.

Mr. George V. Cresson, of the Board of Directors, in answer to a question from Mr. Edward Hurst Brown, stated that those members who availed themselves of all the hospitality of the Club now received more than they paid in.

Professor Spangler stated that for this year the running expenses of the Club, although less than for any previous year, would amount to more than the possible receipts. The cost of publishing the Proceedings in their present style can only be partly paid for by advertisements, and their high character should be kept up. The Club desires not to curtail but to increase its expenses by adding to the attractiveness of its house, but this cannot be done under the present low dues from Resident Members.

Discussion on the Water Supply of Philadelphia was continued.

Business Meeting, December 3, 1892.—President James Christie in the chair; 45 members and visitors present.

The following nominations of officers were made for the year 1893;

For President.—John Birkinbine, proposed by William A. Cooper, seconded by George T. Gwilliam.

For Secretary.—L. F. Rondinella, proposed by Henry Leffmann, seconded by H. C. Lüders.

For Treasurer.—T. Carpenter Smith, proposed by John C. Trautwine, Jr., seconded by John E. Codman.

The President appointed the following Committee to make the other necessary nominations, as provided for in the By-Laws, Article III, Section 2: Messrs. Wilfred Lewis, Henry G. Morris, A. Falkenau, A. Beardsley and Edward Hurst Brown.

Directors H. W. Spangler, David Townsend, John E. Codman, James Christie and Wilfred Lewis proposed to amend Article VII, Section 2, by substituting "$15.00" for "$10.00," and adding the clause "after January 1, 1893," so that the section as amended would read:

"The annual dues of all Resident Members and Associates, after January 1, 1893, shall be $15.00, and of Non-Resident Members, $5.00, payable yearly in advance."

At the request of the Chair, Mr. Townsend, Chairman of the Finance Committee, stated the approximate income and expenses of the Club, which showed an unavoidable annual deficit.

The Tellers reported the following gentlemen elected to Active Membership: Messrs. Francis Henry Thomas, William Copeland Furber, S. Norris Craven and John F. Ostrom.

Resignations from Active Membership were accepted from Messrs. R. Taylor Gleaves, Louis H. Barnard, W. S. Putnam, Philip Pistor and William L. Ziegler.

The Secretary read a communication from Mr. O. Chanute, describing the plan which had been adopted for inviting the engineering societies of this country and abroad to the Engineering Congress of the Chicago World's Fair.

Mr. F. H. Lewis called attention to the act of leading architectural societies of this city in passing a resolution to expel any member who submitted plans for the Bourse, because it was specified that the architect should be associated with an engineer. He suggested the matter as a fit and proper subject of discussion for the Club. No action was taken.

A communication was presented from the American Philosophical Society, calling attention to the one hundred and fiftieth anniversary of its foundation, which will be celebrated in May, 1893, and asking for the appointment of a delegate from the Club to present papers by title. Action was deferred until next meeting.

Mr. G. T. Gwilliam read a paper on "The Heating of Dwellings from a Sanitary Point of View." (Published under "Notes and Commucations.")

The Secretary read a paper by Mr. Charles S. Churchill, upon "High Speed on Railways from a Maintenance of Way and Engineering Standpoint." Mr. Churchill requested that an abstract be prepared and the subject be held open for discussion at the next meeting. It was so ordered. (Published in this number.)

Regular Meeting, December 17, 1892.—President James Christie in the chair; 45 members and visitors present.

Mr. Edward Hurst Brown read a paper on "Paint as Used on Engineering Constructions," in which he described the composition of paints for use on wood and metal surfaces, with particular attention to the proper material to use on structural work. (Published in this number.)

Mr. E. V. d'Invilliers called attention to the death of Mr. Joseph N. Du Barry, Vice-President of the Pennsylvania Railroad Company, and for twelve years an Active Member of the Club. Upon motion the Chair appointed a committee of three to draft suitable resolutions.

The Secretary opened the discussion on "High Speed on Railways" by calling attention to the run of a Philadelphia and Reading express train on November 18th, between Philadelphia and New York, as recorded in the *Engineering News* of December 8th. It made the highest record yet attained, viz., 97.3 and 94.73 miles per hour, the highest previous record having been 91.7 miles per hour, made last February by the same engine, which broke the earlier record of 90.5 miles per hour, made by an engine and one car on the same road in August, 1891.

Mr. John C. Trautwine, Jr., continued the discussion, as published in this number.

ABSTRACT OF MINUTES OF THE BOARD OF DIRECTORS.

October 1, 1892.—Present: President James Christie, Directors John E. Codman, Strickland L. Kneass, Wilfred Lewis and H. W. Spangler, also the Treasurer and the Secretary.

The President reported that, during the summer recess, the Finance Committee had been arranging a new set of books and would be able to make a report to the Board once a month on the financial condition of the Club, and that their first report would be ready for presentation at the next meeting of the Board.

A letter from Professor H. W. Spangler was presented, in which he offered his resignation from the Board, as he felt his increased engagements would prevent his serving properly on the Publication Committee and otherwise. He withdrew it, however, upon Mr. Kneass' proposing to change official places with him on the Board's Committees, which proposal met with unanimous approval.

The Secretary presented a letter from the agents of the World's Fair Co-operative Bureau, offering to rent the Club quarters in the apartment house, "The Beveridge," during the World's Fair. No action was taken on the matter.

October 15, 1892.—Present: President James Christie, Directors George V. Cresson, Wilfred Lewis, H. W. Spangler and David Townsend, also the Secretary.

The Finance Committee presented a trial balance and abstract from same, showing the financial condition of the Club. The Committee stated in their report that, while there was a balance on hand October 1st of $32.82, there would be no income until January 1st, and the running expenses for October, November and December would amount to at least $800, so that a deficit at the end of the year would be inevitable. The report also explained that the new set of books were opened from September 1st, and are now written up to date and balanced, and it closed with a request that the Secretary's assistant be authorized to have charge of all the books. Upon motion the report was accepted, and the Secretary's assistant was ordered to take charge of the Treasurer's books, under the direction of the Finance Committee.

November 19, 1892.—Present: President James Christie, Vice-Presidents F. H. Lewis and P. G. Salom, Directors George V. Cresson, Strickland L. Kneass, Wilfred Lewis and H. W. Spangler, also the Secretary.

The Finance Committee reported the condition of the Treasury at this date to be as follows:

Cash on hand	$128 09
Unpaid bills	758 76

The President suggested that a detailed statement of total amounts received and paid out during the past month be presented by the Finance Committee, at each regular meeting of the Board, with balance at the beginning and end of the month. On motion of Professor Spangler this recommendation was referred to the Finance Committee, with power to act.

A proposal from Mr. John Mulligan was presented by Professor Spangler, offering to furnish the Club certain periodicals bound in a cover, containing also well-selected advertisements. The Library Committee was ordered to accept this offer, as it applied to desirable periodicals not on the exchange list of the Club.

Mr. Kneass reported the cost of issuing Vol. IX, No. 4, October, 1892, of the Club's Proceedings to be as follows:

Printing	$307 00	
Illustrations	57 00	
Postage	50 00	
		$414 00
Value of advertisements		216 00
Balance		$198 00

The Revision Committee reported on a revised Charter and By-Laws, with the probable cost of affecting the proposed changes. It was thought desirable that at least the radical changes should be announced at the next meeting of the Club and explained by the members of the Board.

The Secretary read a letter from Mr. Charles Annear, asking permission to publish a List of Members of the Club, in connection with well-selected advertisements, in the style which he used last year. The Board directed that he be allowed to do so, and that the Secretary furnish him with a corrected list of members.

The Secretary also read two letters subscribing to the Engineering Headquarters to be maintained during the Chicago Exposition, and reported that at present the money subscribed for this purpose was kept in the same account with the other money in the Treasurer's hands. He was directed to notify the Treasurer to keep it in future in a separate account, which should not be used for other purposes.

December 17, 1892.—Present: President James Christie, Directors John E. Codman, Strickland L. Kneass, Wilfred Lewis, H. W. Spangler and David Townsend, also the Secretary.

The Finance Committee presented the Treasurer's report to date, with the following summary:

Balance from last report	$128 09	
Amount received since last report	275 00	
		$403 09
Amount paid out since last report		155 85
Balance on hand December 17th		$247 24

The Secretary presented letters from Messrs. John W. Cloud and S. M. Vauclain, with regard to the Club's contribution toward the maintenance of an Engineering Headquarters in Chicago during the coming Exposition, and he was instructed to inform those gentlemen of what the Club had done, and of the fact that many of the members had already contributed through the National Societies. The Secretary was also instructed to prepare a circular-letter, in the name of the Board, to send to each member with the notice of the next meeting, requesting those who had not already done so to send their contributions to this fund as soon as possible.

A letter was presented from Mr. Amasa Ely, suggesting a plan by which the Club might own its own house. The Secretary was instructed to inform Mr. Ely that the Board would take the matter into consideration.

The Library Committee reported that they had made a contract with Mr. John H.

Mulligan, by which he agreed to furnish the Club with "The Illustrated London News," "Engineer," "Comptes Rendus Hebdomadaires des Seances," "Lumière Electrique" and "Harpers' New Monthly Magazine," for 1893, upon condition that they should be placed in covers which he would furnish, containing selected advertisements upon the inside only. The Board approved the action of the Committee.

It was moved and carried that the telephone be discontinued.

The President appointed the following Auditors and Tellers for 1893:

Auditors.—Messrs. Edward Hurst Brown, H. C. Lüders and Henry G. Morris, with Messrs. Gratz Mordecai and E. V. d'Invilliers as alternates.

Tellers.—Messrs. G. T. Gwilliam, George W. Irons and H. Warren Hale, with Messrs. C. H. Roney and John S. Mucklé as alternates.

The Publication Committee was given power to increase its membership by adding Club members not on the Board of Directors, but who would assist in carrying on the work of the Committee.

Jas Brickenbrue

Elected President January 21st, 1893, for the Sixteenth Year of the Club, A. D. 1893.

PROCEEDINGS

OF THE

ENGINEERS' CLUB OF PHILADELPHIA.

ORGANIZED DECEMBER 17, 1877.

NOTE.—The Club, as a body, is not responsible for the statements and opinions advanced in its publications.

Vol. X.] APRIL, 1893. [No. 2.

ANNUAL ADDRESS

OF

JAMES CHRISTIE, Retiring President.

Delivered January 21, 1893.

GENTLEMEN:—I congratulate you on the successful issue of another year in the life and work of the Club. A widening field of usefulness and influence is in view, and ours is the duty to prepare for the work that invites us. The members of this organization follow various pursuits, in many cases so diverse as to have little seeming relevancy to each other. Individually we are to a large extent specialists in certain lines, and as such are naturally most interested in topics that relate to our several occupations. Hence it might to some seem difficult to maintain a bond of union of sufficient strength to attract and hold together the dissimilar elements.

Why, might we ask, should any one confine his research to the limited arena of his daily toil? Does not the mind, like the body, become more dextrous by variety of occupation? Does not even personal interest indicate the utility of a comprehensive study of all related facts? We might borrow the idea of the Roman author, but paraphrase his words, "I am an Engineer, and whatever relates to Engineering interests me."

An eminent statesman once said that the efforts of the student should be directed to "learning something of everything, and everything of something." The advice explains itself To no profession is the application more pertinent than to the Engineer's, for his "everything" is world-wide, his "something" is a hidden thought, locked in Nature's grasp, for which he has to wrestle and strive with masterful intensity of mind and purpose. The objects to be won are manifold, but the weapons of attack are similar, and the knowledge to use them is taught by the same masters.

It may be asked: "What relation does the Club bear to the profession at large?" or, further, "Who is the Engineer, and how are his duties defined?"

The objects of this Club, as defined in its Constitution, are "to promote the Arts and Sciences connected with Engineering, to facilitate social intercourse, and to disseminate information amongst its members"—certainly laudable intentions which cannot be too zealously encouraged.

But beyond any formulated phrase exist other objects tacitly understood—a desire to mould an intelligent public opinion in all matters that belong to the profession, and that can be made an effective force only by unity of action and the power of numbers.

Such an effort can always be beneficially exerted by a body whose fundamental principles are derived from the most substantial of truths—mathematical science; who are habitually trained to seek for facts and reject fallacies, and whose extensive curriculum, confined to a logical series of material veracities, has no room for the speculations of sciolism, or the artifices of politics.

Considering the wide diversity of pursuits, and apparently distinct occupations, into which the profession of Engineering subdivides, it might appear that the name, "Civil Engineer," was a generic term, rather than a concrete and distinctive title; but a little reflection will demonstrate the common origin, the solidarity of principles and interests which subserve and stimulate the general advancement, and the enduring, but elastic, links which bind together the diverging ranks.

The century is not yet complete since the title of Civil Engineer was given to the profession, and since Telford enunciated his broad but uncertain definition—" All whose profession it is to direct the great sources of power in Nature for the use and convenience of man." The engineer controls so vast a domain that its boundaries cannot be distinctively defined. On the one hand it merges into the imaginative realm of the fine arts, on the other it penetrates the workshop of the mechanic. He consults both the laborer in the quarry and the scientist in the studio. The profession employs the pencil of the artist as well as the chisel of the artisan. The mind of the mathematician and the active energy of the man of affairs are engaged in its service. It holds dominion over all the elements, and throughout the vast field of human activity its presence is everywhere manifest; its functions are supreme. For the successful and economical solution of the multiform problems that confront the engineer, a free interchange of thought and experience is most desirable, and the appreciation of this fact accounts for the numerous associations of the profession in civilized lands, and is the principal reason and incentive for the existence of such organizations as ours.

The art of Engineering co-existed with primeval civilization. The names of the engineers who practised their art in the valleys of the Euphrates and the Nile are lost in oblivion, but the ruins of their work attest their ingenious skill. The ancient historian was more concerned with the monarchs and warriors of those eras of ceaseless warfare than with the heroes of the peaceful arts; and yet their work emanated from a class who, in the words of a recent writer, have done more for human civilization than all the efforts of kings and statesmen.

When Rome was mistress of the world her engineers built aqueducts, bridges and enduring roads, whose remains are yet sublime; and on sea and land, in the depths of the mine and on the mountain's summit—everywhere, to-day, the art of the engineer exists. We witness the trophies of his skill

> " In the steamship, in the railway, in the thoughts that shake mankind."

The science of Engineering is comparatively modern. Until a

recent era the labor of the mathematician was largely devoted to the abstract science or to its application in the solution of astronomical problems. The philosopher devoted himself largely to metaphysics. The tracing of material effects to their causes was not prosecuted on any consistent and rational basis.

The foundations were begun by Bacon, Descartes and Galileo, who resented or discarded the dictation of dogmatic authority in scientific thought. They cleared the way for the great mathematicians, represented by Newton, by Leibnitz and Euler, and their host of illustrious successors, who evolved the infinitesimal calculus, established the laws of pure mechanics, and fortified natural philosophy behind impregnable and imperishable bulwarks. Their work was supplemented by the succeeding physicists, the pioneers in the practical application of the science of matter and motion. Geology and chemistry were re-created, and stripped of the old mystic conceptions they attained a sturdy growth; the one revealing the composition and formation of the terrestrial surface, the other the action and effects of the infinite combinations that occur amongst the elements. Electrical science was founded when any useful application of it was considered the vision of the dreamer.

The age of experiment began, and the introduction of the steam-engine involved the science of thermodynamics, as the novel structures that followed the steam-engine involved the science of applied mechanics, and these cognate sciences all unite in a grand summation—the science of Engineering—with a wealth of possibility that baffles the imagination, and affording an ample base for a superstructure whose scope and magnitude the most hopeful optimist may not discern in the elusive vista of the future.

In this pre-eminently industrial age the art of the Engineer has a more extensive opportunity for practice than ever before. This is so evident a fact to those whose memory recalls a few decades, that it needs no argument to prove it. Even in the past century consumption was apparently outstripping production, and gloomy theories were surmised by the social philosophers predicting calamity as a result.

The invention of the steam-engine and its application to the

arts of production, and distribution over land and water, acted as a material stimulus, exceeding all anticipation, so that now the ability to produce has outgrown the ability to consume to such an extent that combinations exist whose object is to repress the overproduction of certain staples. It may be proved by future commentators that this incentive to production and distribution marked an important advance in civilization, in which the Engineer accompanied the Ecclesiast as a missionary; or that material methods are as essential as moral agencies in effecting the regeneration of society. At no previous time has the old order given place to the new with greater rapidity than at present, and while the process, under the stress of competition, works with hardship to the few, its eventual result is beneficial to the many; and the curious anomaly is presented of reduced cost of production without corresponding reduction in the compensation of the producer.

Agriculture has profited by the adoption of appliances for facilitating the cultivation and gathering of the products of the soil, but much is to be done in the application of mechanical energy on the farm, and transportation of material to places for general shipment, the storage of water to alleviate loss in seasons of drought, and the irrigation of arid lands. Per contra, the controlling of disastrous floods, especially on the large rivers, is an endless question. The Mississippi problem alone is an intricate one that awaits some satisfactory solution, and one which, amid diversity of opinion, can only be solved by the scientific method of patient experiment and intelligent study and observation.

The railroad—that index of progress and civilization—will record its 170,000 mile mark in the country this year. More substantial road-beds and bridges, bearing heavier burdens than heretofore, have resulted in economy of transportation, and nowhere is merchandise more cheaply transported, or passengers more rapidly and comfortably carried, than on our American railroads. More careful and systematic methods of dispatching trains must be devised to obviate the too numerous accidents that occur, and which remain the principal stigma on our railroad system. The ever-increasing demand for higher rates of speed has brought passenger traffic close to the practical limits

of safety under existing conditions. The abolition of crossings at even grade, straightening lines to lessen unnecessary curvature, and reduction of gradients, will remove some objections to greater speed, but the great weight of engines and trains remain an impediment. Separate tracks for freight and passenger service, lighter and more frequent passenger trains, impelled by rotary motors, offer advantages that may become practicable.

The whole modern system of life is indissolubly bound up with the railroad, for it is evident that the amplest production implies the most complete means of distribution, consequently the railroad system must grow and develop until civilization wanes, or some better method of transportation is devised.

There are indications of a revival to some extent of the canal system, at least as connections between the principal navigable waters. Several of the projects now contemplated, attract sufficient interest to indicate that the commercial advantages of well-devised canals are still appreciated. As both the great political parties, by their recent declarations, are pledged to promote the construction of the Nicaragua Canal, it is reasonable to infer that an isthmian water-way may soon be completed, and the dream of centuries be realized.

In the production of iron the United States now takes the foremost place among the nations. We are close to the rate of 10,000,000 tons of annual product, of which nearly one-half is converted into steel. The modern blast furnace, steel converter and rolling-mill, have reached a stage of development that is probably near the maximum limit for rapid production. Steel has already become the predominant structural material, verifying Bessemer's prediction, that the age of steel would succeed the age of iron, as surely as the latter succeeded the age of bronze.

In no department of industry is the service of the Engineer in more active demand than in connection with the production and adaptation of this valuable metal. In conjunction with the cheap and reliable hydraulic cements, whose use has been of late so largely extended for foundations and masonry, steel now forms an important element in the construction of large buildings. We shall shortly have an object-lesson at our doors, in the twin miracles in iron, for terminal depots, now under construction by the leading railroad companies.

Matters pertaining to Municipal Engineering have always received considerable attention in the Club. It is to be hoped this will increase instead of diminish, for on this question the average citizen thinks he knows a good deal. Here the philosophy of the late Josh Billings would apply—" Better not know so much than know so many things that ain't so." We know that the many excellent Engineers in the various municipal departments have a continuous struggle against adverse circumstances. It is gratifying, however, to record a marked improvement in all public work during the past few years. An intelligent public sentiment has been created, and is loudly expressed by the people and the press, and the attachment of responsibility to permanent departments instead of shifting representatives, has resulted in improvement.

Hygienic and engineering science now unite in the profession of the Sanitary Engineer, and it is hoped that in the application of correct principles to pavements, drainage, water-supply, etc., society may be less afflicted with the occurrence or spread of that class of disease for which the individual is not directly responsible.

The rural highways in many districts are distinctly inferior in condition, as compared to their state when the farmer was more dependent on them for communication with the towns. There are signs of some reformation at hand, and here the Engineer has a mission to perform, in which he should take a leading part, and be a Moses in successful reform rather than a Jeremiah in useless lamentations.

The passenger railway systems in cities is seemingly in a state of transition. For rapid transit the overhead system is rapidly extending in large cities, and is certainly much preferable to any subterranean method from the traveler's point of view, if not from the householder's, who naturally objects to the maze of structures which mars his landscape. For surface roads, quicker and more cleanly methods of propulsion are now more feasible than that afforded by horses. The subject has been so thoroughly discussed in the Club that it is unnecessary to review it. It is evident, however, that the electric trolley system has found favor with both capitalists and the public. It operates roads in the country aggregating 5,000 miles in length. Bearing less dead load than

any other system that carries its own motors, climbing grades otherwise only practicable with the cable, and interfering less with pavements than the latter, it has commended itself especially to rural and suburban communities, or wherever the public taste has not reached that stage of æsthetic exaltation which objects to the already serious nuisance of overhead wires. The unrelaxed efforts devoted to the improvement of the secondary battery indicates much promise for the electric storage system, and it is claimed by its promoters that it has now attained a more practicable degree of economy that was conceded to it a few years ago.

The application of the electric current to the transmission of power continues to develop rapidly, and is proving a serviceable agent by reason of its flexibility and adaptability. The success of the Lauffen-Frankfort experiment, if followed by equal results from the Niagara generators, will result in a further evolution of the system. We have abundant water-power, inconveniently situated for direct utilization, which may be employed economically at distances hitherto impracticable. Then electric transformations of natural power into light, heat and motion will render possible the establishment of new industrial communities.

Electrolysis, with its manifold and undeveloped application to the arts, will have extensive employment, and it is no wild speculation to predict that the application of electricity to industrial purposes may effect a revolution in the coming century, similar to that already obtained from the use of steam in the present century.

So in casting a prospective glance at the work in view, and considering only a few salient features, without reference to the countless objects to which the attention of the Engineer is now and will be directed; it is evident that the problems to be solved, the obstacles to be overcome, and the difficulties to be surmounted, demand the devotion and courage of the rising generation. The heritage they possess, in the works and triumphs of the past masters, ought to serve equally as an aid and an inspiration. As much has been given, so much will be expected, and zeal and industry, skill and intelligence, all combined with manly rectitude, cannot fail to ennoble them in the ranks of mankind, to dignify their profession, and bring honor to their country.

VII.

RECENT EXPERIMENTS ON THE FLOW OF WATER OVER WEIRS.

By M. Bazin, Inspector-General of Bridges and Highways.

Reprint from Annales des Ponts et Chaussées, January, 1890.

Translated by Arthur Marichal and John C. Trautwine, Jr., Active Members of the Club.

Part II (*c*).

Distribution of Velocities and Pressures in the Interior of the Nappe.

It now remains, in order to close our discussion of the nappe, to examine the distribution of the pressures and velocities within it. The instrument used for this purpose is represented in Fig. 2, Pl. 4. It consists of a copper blade, *A N*, 0.50 m. (20 inches) in length, 3 mm. (0.12 inch) thick, which penetrates the nappe, as shown. The presence of this strip, sharpened on its upper edge and perfectly smooth on its sides, does not disturb the flow. The lower edge carries two small brass tubes of 2 mm. (0.08 inch) bore, Fig. 6, placed one above the other and soldered into a groove.

One of these tubes has its up-stream opening at the upper extremity *A* of the instrument (Figs. 4 and 5), the other on its side at *B*. The diameter of these small orifices is 1.5 mm. (0.06 inch) and their distance apart is 1 cm. (0.39 inch). The apparatus is plunged into the nappe, with the plane of the blade vertical and parallel to the axis of the channel. The orifice *B* (Fig. 4) is exactly flush with the side of the blade, and therefore parallel to the direction of the flow. Hence it receives only the local hydrostatic pressure at its mouth; but the orifice *A* of the other tube (which forms a sort of Pitot's tube), with its opening facing up-stream, receives directly the impact of the fluid vein approaching it. The pressures exerted upon the two orifices are transmitted by means of the brass tubes and of leaden and rubber connecting pipes (Figs. 2, 3, 6 and 7), to two vertical glass-tubes *T*, *T'*, (Fig. 3) 8.5 mm. (0.33 inch) in diameter, attached to a board which is fixed to the side of the lateral trench from which the

study of the profiles of the nappes was made. The variations of level in these two tubes, which are entirely open at their upper ends, indicated, as we shall proceed to explain, the distribution of the pressures and velocities. A third glass tube T'', communicating with the chamber above the weir where the heads were observed, indicates the heads h, in order that their accidental variations may be followed, although this is also given by the dial-floats. (Proceedings, Vol. VII., No. 5, p. 262, and Figs. 4, 5 and 6, Pl. 2.)

The copper blade is fixed at the extremity of a strip of wood NO, which is movable about a pivot O, rigidly secured in the axis of the channel at the level of the crest W of the weir. A pin at N, carried by a slide-rule, moves in a longitudinal groove, arranged at the other end of the wooden strip. If now we raise or lower the slide-rule in the fixed vertical line $R\,R$, the end A of the instrument is compelled to describe the arc of a circle of 1.50 m. (4.92 feet) radius. At the beginning of each experiment the orifices were placed at the level of the crest W of the weir. Their height z above the crest ($C\,D$, Fig. 8) at any point of their course, is readily deduced from the reading $M\,N$ on the slide-rule $R\ R$. In fact, r being the radius of the arc described by the orifice, and $M\,N$ the reading on the slide-rule $R\,R$, we have:

$$z = C\,D = r \sin M\,O\,N$$

$$\mathit{Tan}\ M\,O\,N = \frac{M\,N^*}{N\,O}$$

Before proceeding with the experiments it was necessary to fill the tubes with water, so as completely to expel the air. We accomplished this by attaching to the tops of the glass tubes T, etc., rubber tubes which were held up to a certain height and into which water was poured, expelling the air bubbles through the orifices A and B.

Having filled the tubes in this way, the level of the crest of the weir was marked upon them. This operation is attended with some difficulty if the orifices are allowed to open freely into the air. Owing to the influence of capillarity and to a bend in one of

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* The radius r being = 1.50 m. for the orifice A and 1.49 m. for the orifice B, the distance $N\,O$ = 1 m. and the angle $M\,O\,N$ remaining quite small in all positions the instrument, z differs but very little from $\frac{3}{2}\,M\,N$.

the brass tubes, the level of the water after the filling was not the same in both of the glass tubes. In order to eliminate this source of error the weir was covered with a certain depth of still water, in which the two orifices A and B were then immersed. All difference of level between the three tubes, indicating the head, the pressure and the velocity, then disappeared, the three columns of water remaining exactly at one level. Suppose, for instance, that we cover the crest of the weir with a layer of still water 0.25 m. deep, and that the water then rises to 0.875 by the scale attached to the tubes. It is clear that the level of the crest (which is also the level of the two orifices of the instrument at the beginning of the experiment) corresponds, by the same scale, to 0.875–0.250 or 0.625.* In other words we have only to deduct 0.625 from the readings of the scale in order to refer them all to the level of the crest of the weir, which is taken as the datum.

This point once established, let us suppose, in place of the layer of still water 0.25 m. deep, the nappe flowing over the weir under a head $h = 0.25$ m. The level in the tube indicating the heads will then stand at 0.25, but those in the other two tubes will give different values. Let A be the reading in the tube indicating the velocities and communicating with the end orifice A, and B the reading in that indicating the pressures and communicating with the lateral orifice B. When the orifices are raised to a height z above the crest, the pressure P, measured as a head of water, will be given by the difference of level, $B - z$. As to the other tube, the orifice of which receives, besides the pressure P, the impact of a liquid filament moving with the velocity u, the difference of level $A - z$ corresponds to $P + \frac{u^2}{2g}$, from which we have:

$$\frac{u^2}{2g} = A - (z + P) = A - B$$

and

$$u = \sqrt{2g(A - B)}.$$

* Owing to the capillarity of the tubes the level of the tops of the three columns is in fact a trifle higher than that of the crest of the weir. We are satisfied, from a number of observations, that this super-elevation, for the lower part of the meniscus, by which the scale was always read, was 1 mm. = 0.039 inch. The true level of the crest was, therefore, in the above example, 0.624, a result which we verified by exact measurement with a spirit-level.

It will be noticed that the equation for u contains no experimental coefficient. In fact the instrument does not differ essentially from the Darcy tube employed in our first experiments, and the coefficient for the calibration of that tube, determined by a number of observations, had been found exactly equal to unity. In both instruments, the up-stream orifice is a small ajutage normal to the current, and the lateral orifice opens perfectly flush with a lateral surface over which the liquid filaments flow tangentially. The sole difference consists in this, that in the Darcy apparatus the tubes corresponding to the two orifices are joined at their upper extremities, in order that the water in them may be raised by suction, whereas in the instrument that we have employed the two tubes are separated and we may thus obtain separately the pressure and the velocity. In order to reassure ourselves as to the identity of the results given by the two instruments, we have used them separately in making numerous velocity-measurements in a channel with undisturbed flow, and the complete accordance of their indications has demonstrated that the coefficient of the newer instrument is also unity. Upon this subject see also the memoir of M. Ritter: "Sur quelques changements dans les dispositions et les procédés de tarage des instruments de jaugeage." (Upon certain changes in the construction and rating of instruments for the measurement of flow).—*Annales des ponts et chaussées*, 1885, 1*er Semestre*). In this memoir M. Ritter, investigating the conditions which the lateral orifice must fulfill, gives the name of static ajutage to this orifice, past which the filaments flow tangentially, so that its indications depend solely upon the hydrostatic pressure and not upon the velocity. He shows that this was the case for the Darcy tube, the coefficient of which must therefore be unity, as it is also shown to be by experiment. Our experiments upon the distribution of the pressures and velocities within the nappe were made with the weir 1.13 m. (3.7 feet) high, with six different heads, viz.: 0.15, 0.20, 0.25, 0.30, 0.35, 0.40 m. (5.9 to 15.75 inches), the greatest care being taken to keep each of these heads constant. For each of them the instrument was so placed that in its horizontal position the distance from the orifice B to the crest was 0.25 h. If we refer to the normal profile of the nappe, Fig. 2, Pl. 4, we see that upon raising the instrument the orifices enter

the nappe nearly at the summit of the lower curve. The results are recorded in the following tables. The first column indicates the ordinate z above the crest of the weir,* the second and third columns the levels A and B in the tubes indicating the velocity and the pressure respectively. From what has been said it follows that

$$A = z + P + \frac{u^2}{2g},$$

$$B = z + P.$$

Finally, the last two columns give respectively P and $\frac{u^2}{2g}$.

Measurement of the Pressures and Velocities within the Nappe.—Weir 1.13 Meter (3.7 Feet) High.

Experiments Nos. 2, 4 and 6, October 21 and 22, 1889. Temperature of water, 10.5° C. (50.9° Fahr.)

Experiments Nos. 1, 3 and 5, November 26, 1889. Temperature of water, 6° C. (42.8° Fahr.)

All the values are given in millimeters.

z Height of orifice above crest of weir.	Reading of the Tube Measuring the — Velocities. $A = z + P + \frac{u^2}{2g}$	Reading of the Tube Measuring the — Pressures. $B = z + B.$	Pressure. $P = B - z.$	Velocity Head. $\frac{u^2}{2g} = A - B.$
Experiment No. 1.—Head = 0.15 m. = 5.9 inches.				
17	143	19	2	124
21	150	29	8	121
26	150	39	13	111
30	151	43	13	108
33	150	57	24	93
38	151	57	19	94
42	151	73	31	78
48	151	73	25	78
55	151	85	30	66
62	150	86	24	64
70	150	98	28	52
77	150	98	21	52
85	151	106	21	45
92	151	106	14	45
100	151	114	14	37
107	150	114	7	36
115	151	117	2	34
119	151	119	0	32

* The two orifices being distant 1 cm. (0.39 inch) from each other, their heights, except when the instrument is horizontal, are not rigorously the same. The ordinate z, given in the tables, is that of the orifice A, or of the up-stream end of the instrument.

z Height of orifice above crest of weir.	Reading of the Tube Measuring the — Velocities. $A = z + P + \frac{u^2}{2g}$	Reading of the Tube Measuring the — Pressures. $B = z + B.$	Pressure. $P = B - z.$	Velocity Head. $\frac{u^2}{2g} = A - B.$
Experiment No. 2.—Head = 0.20 m. = 7.87 inches.				
23	192	26	3	166
26	201	34	8	167
32	201	42	10	159
40	203	62	22	141
47	201	68	21	133
54	202	84	30	118
61	203	90	29	113
69	202	100	31	102
76	202	110	34	92
84	202	114	30	88
91	202	121	30	81
99	202	128	29	74
106	202	131	25	71
114	202	136	22	66
121	202	141	20	61
129	202	144	15	58
136	202	147	11	55
144	202	150	6	52
151	201	153	2	48
157	203	157	0	46
Experiment No. 3.—Head = 0.25 m. = 9.84 inches.				
30	247	36	6	211
34	250	45	11	205
37	250	50	13	200
41	249	59	18	190
43	250	65	22	185
46	250	73	27	177
49	251	77	28	174
54	250	88	34	162
58	250	93	35	157
64	251	106	42	145
70	251	111	41	140
78	251	125	47	126
85	251	128	43	123
93	251	143	50	108
100	251	144	44	107
108	251	156	48	95
115	251	157	42	94
123	251	166	43	85
130	252	168	38	84
138	251	174	36	77
145	252	176	31	76
152	252	179	27	73
159	251	183	24	68
167	253	186	19	67
174	252	188	14	64
182	251	192	10	59
189	251	194	5	57
195	251	195	0	56

z Height of orifice above crest of weir.	Reading of the Tube Measuring the — Velocities. $A = z + P + \frac{u^2}{2g}$	Reading of the Tube Measuring the — Pressures. $B = B - z.$	Pressure. $P = B - z.$	Velocity Head. $\frac{u^2}{2g} = A - B.$
Experiment No. 4.—Head = 0.30 m. = 11.8 inches.				
34	288	40	6	248
39	300	52	13	248
47	295	69	22	226
55	302	92	37	210
62	298	104	42	194
70	302	122	52	180
77	299	132	55	167
85	302	143	58	159
92	300	150	58	150
100	302	157	57	145
107	301	165	58	136
115	302	176	61	126
122	302	177	55	125
130	302	188	58	114
137	303	190	53	113
144	303	195	51	108
151	303	198	47	105
159	302	202	43	100
166	303	205	39	98
174	302	211	37	91
181	301	214	33	87
189	302	217	28	85
196	303	219	23	84
203	303	218	15	85
210	303	224	14	79
218	303	229	11	74
225	303	229	4	74
231	303	231	0	72
Experiment No. 5.—Head = 0.35 m. = 13.8 inches.				
41	339	46	5	293
45	349	57	12	292
49	349	67	18	282
58	350	85	27	265
67	350	104	37	246
73	352	118	45	234
79	350	123	44	227
87	350	139	52	211
95	350	150	55	200
102	351	159	57	192
110	350	167	57	183
117	352	181	64	171
125	351	186	61	165
132	352	193	61	159
139	352	197	58	155
146	353	207	61	146
154	352	212	58	140
161	352	216	55	136
169	352	220	51	132
176	351	229	53	122
183	352	229	46	123

z Height of orifice above crest of weir.	Reading of the Tube Measuring the — Velocities. $A = z + P + \frac{u^2}{2g}$	Pressures. $B = z + B.$	Pressure. $P = B + z.$	Velocity Head. $\frac{u^2}{2g} = A - B.$
	Experiment No. 5.—(Continued.)			
191	353	236	45	117
198	353	238	40	115
205	352	243	38	109
213	351	247	34	104
220	353	252	32	101
227	352	253	26	99
234	352	258	24	94
242	352	260	18	92
249	353	264	15	89
256	353	265	9	88
263	352	268	5	84
268	353	268	0	85
	Experiment No. 6.—Head = 0.40 m. = 15.8 inches.			
46	374	53	7	321
49	387	59	10	328
54	398	70	16	328
65	403	94	29	309
72	404	119	47	285
80	403	135	55	268
87	403	151	64	252
94	404	167	73	237
102	406	175	73	231
109	405	183	74	222
117	404	190	73	214
124	405	196	72	209
132	404	205	73	199
139	405	212	73	193
147	405	220	73	185
154	405	227	73	178
162	405	234	72	171
169	405	240	71	165
176	405	245	69	160
183	406	243	60	163
191	405	246	55	159
198	405	251	53	154
205	405	256	51	149
212	405	261	49	144
220	406	266	46	140
227	405	269	42	136
234	405	272	38	133
241	404	274	33	130
249	405	278	29	127
256	405	281	25	124
263	406	285	22	121
270	405	288	18	117
277	408	292	15	116
284	406	295	11	111
291	405	298	7	107
298	405	302	4	103
304	405	304	0	101

It will be noticed that during the entire duration of each experiment and for all positions of the orifice A in the interior of the nappe, the height of the column in the tube A or T' above the crest remains practically constant and equal to h; in other words, that

$$z + P + \frac{u^2}{2g} = h .$$

The theorem of D. Bernoulli is thus directly and very strikingly verified.*

Observing more closely, we observe that the sum of the three heads z, P and $\frac{u^2}{2g}$, in fact slightly *exceeds* h. The excess, scarcely perceptible for the head of 0.15 m. (5.9 inches) increases to nearly 5 mm. (0.2 inch) for a head of 0.40 m. (15.75 inches). This circumstance may be explained by observing that the head h, which appears in the second member of the above equation, is regarded as being measured at a point where the velocity is zero; whereas there actually is, at the point where h is measured, a velocity of approach U; and h, as recorded by the tube T'', should, therefore, be increased by $\frac{U^2}{2g}$, the successive values of which, increasing with the head, are, for the six experiments, 0.4 mm., 0.8 mm., 1.5 mm., 2.4 mm., 3.6 mm. and 5.0 mm. (0.016, 0.031, 0.059, 0.094, 0.14 and 0.2 inch). In other words, h in the equation should be multiplied by 1.003, 1.004, 1.006, 1.008, 1.010 and 1.013 (mean: 1.007 h). Taking the mean of the observed values of A, as given in the tables, we obtain for the sum $z + P + \frac{u^2}{2g}$, somewhat irregular values, the mean of which is 1.006 h.

Examining next the values of P and of $\frac{u^2}{2g}$, corresponding to the different heads, we recognize that they vary proportionately with h; in other words, that the values of $\frac{P}{h}$ and of $\frac{u^2}{2gh}$, corres-

* Bidone had already observed that upon plunging into the nappe a bent tube, opening up-stream, the water rises in the tube to the level of the water up-stream, "where the surface may be regarded as a horizontal plane."—*Mémoires de l'Académie de Turin*, 1824.

ponding to a given value of $\frac{z}{h}$, are constant throughout the tables. We may, therefore, taking $\frac{z}{h}$ as abscissæ, represent by a single curve the variation of the values of $\frac{P}{h}$, and similarly that of the values of $\frac{P}{h} + \frac{u^2}{2gh}$. This graphic representation is given in Plate 4, where the scale of the abscissæ $\frac{z}{h}$ is 0.01 m. = 0.02, and that of the ordinates $\frac{P}{h}$ or $\frac{P}{h} + \frac{u^2}{2gh}$, is 0.01 m. = 0.05.

Each of the experimental values of these last two quantities is indicated in the diagram by a point designated by the number of the corresponding experiment. The height z not being exactly the same for the two orifices A and B, the two points corresponding to the values of P and of $P + \frac{u^2}{2g}$ obtained with a given position of the instrument do not occur upon exactly the same ordinate.*

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* The construction of these curves requires some explanation. We have already seen that the profiles of the sheets for different heads are similar figures, the absolute dimensions of which increase proportionately with h. At the beginning of each experiment we placed the orifice B at a distance from the crest equal to 0.25 h. In other words, at homologous points; and in raising the instrument the orifice penetrated into the sheet at the summit of the lower curve, the height of which above the crest is $0.112 \frac{z}{h}$. But the radius of the arc described by the orifice being invariable, the points where it emerges from the upper surface of the sheet are no longer homologous points for the different heads, as will be seen in Fig. B below. In this figure the profiles of the nappes for the extreme heads of 0.15 m. and 0.40 m. are made to coincide by drawing them to the same scale, and the dotted curves $b\ b'$ and $b\ b''$ represent the two arcs (for the two heads respectively) described by the orifice B, with its radius of 1.49 m., beginning at a point b, distant 0.25 h from the crest. The curve $b\ b'$ represents the arc described under a head of 0.15 m., and the curve $b\ b''$ that described under a head of 0.40 m.

It will be noticed that the elevations of the points of emergence b' and b'' are 0.769 h and 0.751 h respectively. If it had been necessary to take account of these differences, the tracing of the curves of pressure would have been needlessly complicated. We have, therefore, assumed for the point of emergence of the orifice B the mean ordinate 0.760 h, whatever might be the head. The orifice A being situated at a constant distance of 0.01 m. (0.39 inch) in advance of the orifice B, its positions

Curves of the Values of $\frac{P}{h} + \frac{u^2}{2gh}$.

The points corresponding to the sum $\frac{P}{h} + \frac{u^2}{2gh}$ are distributed with remarkable regularity in a very narrow rectilinear zone. Referring again to the equation of D. Bernoulli, in which, as just explained, h must be multiplied by a coefficient k, a little greater than unity, we have

$$Z + P + \frac{u^2}{2g} = k\,h,$$

or, dividing by h, and putting, for brevity,

$$\frac{z}{h} = x \qquad \text{and} \qquad \frac{P}{h} + \frac{u^2}{2gh} = y,$$

$$x + y = k,$$

an equation which, taking k to vary from 1.003 to 1.013, will represent parallel straight lines diverging gradually from the axis of x. These lines being very close together, we will confine ourselves to tracing that which corresponds to the mean value $k = 1.006$. The ordinate corresponding to the abscissa $\frac{z}{h} = 0.112$ (lower surface of the nappe) is $1.006 - 0.112 = 0.894$. Approaching this limit the line evidently leaves below it the points obtained by direct experiment.

It might, indeed, be asked whether the instrument acts normally in the vicinity of the lower surface of the nappe, inasmuch as its blade is then not completely immersed; but no irregularity is noticed near the upper surface of the nappe where the blade is in a nearly similar position.* Furthermore, if we divide the thickness of the nappe into four equal layers, beginning with the lower surface, and if, for each of these layers, we calculate, by

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upon the horizontal passing through the crest of the weir could not be homologous points relatively to the heads, and the discrepancy is greater for the smaller heads. The arcs $a\,a'$, $a_1\,a''$ of 1.50 m. (4.9 feet) radius described by the orifice A under heads of 0.15 m. and 0.40 m. (5.9 and 15.75 inches) respectively are indicated in Fig. A above. The heights of the points of emergence of A vary between 0.791 h and 0.761 h.

* Except as to the groove containing the two small brass tubes, which in one case is immersed and in the other is not.

means of the elements furnished by the tables, the mean values of $\frac{z + P + \frac{u^2}{2g}}{h}$ or of k, we obtain the following figures:

MEAN VALUES OF $\frac{z + P + \frac{u^2}{2g}}{h}$ IN DIFFERENT PARTS OF THE NAPPE AND UNDER DIFFERENT HEADS.

$\frac{z}{h}$	HEADS IN METERS.					
	0.15	0.20	0.25	0.30	0.35	0.40
0.12 to 0.28	1.002	1.008	0.999	0.998	1 000	1.004
0.28 to 0.44	1.005	1.012	1.004	1.006	1.004	1.012
0.44 to 0.60	1.003	1.011	1.006	1.009	1.006	1.013
0.60 to 0.76	1.006	1.010	1.006	1.009	1.007	1.013

We notice that the values of the ratio k increase as we pass from the lower to the upper surface of the nappe. This ought to be the case; for if we are to apply the formula of D. Bernoulli to any particular filament it will no longer suffice to assume, as we did at first glance, that the mean velocity in the channel of approach is the velocity of approach of that filament. For the lowest filaments we must take the bottom velocity in the same channel, and for the upper filament the surface velocity; and the two resulting values of k will be very different. For a head of 0.40 m. (15.75 inches), this value would in fact vary from 1.006 (lower filament) to 1.020 (upper filament). The variations of k in the preceding table are thus quite naturally explained. The anomalies which they exhibit are not surprising, considering the delicacy of the experiments, in which an accidental difference of 1 or 2 mm. modifies considerably the values of the ratios.

CURVE OF PRESSURES.

The points indicating the values of the pressure $\frac{P}{h}$ are by no means so regularly disposed, and their scattered locations betray

numerous anomalies which contrast singularly with the uniform results obtained from the other tube. These anomalies may be explained, up to a certain point, by an accidental obliquity of the blade, which, owing to flexure of the instrument, might at times fail to be parallel to the direction of the current. We can understand that in this case the orifice B, being to some extent either protected from or exposed to the action of the current, notable variations would occur in its indications of the pressures; such obliquity having, on the contrary, but little effect upon the orifice A, which would remain nearly normal to the liquid filaments. This explanation is, however, insufficient, and we must conclude that the variations in the pressure are inherent to the nature of the phenomenon. Notwithstanding the apparent regularity of the flow, oblique currents, due to the passage of eddies produced in the channel of approach, always exist in the interior of the mass. Projecting ridges are often seen to form on the surface of the nappe, moving transversely, little by little, before disappearing. Their passage is certainly accompanied by sensible perturbations, but it seems that the variations of the pressure are compensated by corresponding variations in the velocity, so that the sum $P + \frac{u^2}{2g}$ remains nearly constant.

The curve of $\frac{P}{h}$ in the figure (Fig. 1, Plate 4), therefore represents only a mean condition, about which the pressures constantly vary. It necessarily originates upon the axis of x at the abscissa $\frac{z}{h} = 0.112$ (the elevation of the summit of the lower surface of the nappe) and terminates at the abscissa $\frac{z}{h} = 0.760$ (mean upper surface). The maximum pressure $P = 0.18\ h$ corresponds to the abscissa $\frac{z}{h} = 0.34$, and is found nearly at one-third of the thickness of the nappe from the lower surface. These results accord well with those arrived at by M. Boussinesq. In the first of his works, quoted above, he gives $P = 0.19\ h$ for the maximum of P, and in his recent study, $P = 0.17\ h$, the theoretical maximum corresponding to the abscissa $z = 0.37\ h$.

The surface of the nappe is subject to continual oscillations, the amplitude of which appears to reach approximately $\frac{h}{100}$; and the value of the elevation $\frac{\epsilon}{h} = 0.112$ is only a mean, the actual elevation at a given instant varying, it may be, several thousandths in excess or in deficiency. This circumstance explains the fact that the instrument shows pressures somewhat too great between the abscissæ 0.11 and 0.15. We have indeed obtained, owing to the oscillation of the nappe and to the irregular action of the water against the blade, a few indications of pressure below the limit of 0.112; but we may properly neglect these results, for they are evidently beyond the pale of the normal conditions of the phenomenon.

Curve of Velocities.

Deducting from the ordinates of the straight line

$$\frac{P}{h} + \frac{u^2}{2gh} = 1.006 - \frac{z}{h}$$

those of the curve of pressures $\frac{P}{h}$ we obtain the curve of the values of $\frac{u^2}{2gh}$, and then, by means of a simple extraction of the square-root that of $\frac{u}{\sqrt{2gh}}$. By inspection of the latter we see that the velocity decreases from $u = 0.946\sqrt{2gh}$ (at the lower surface of the nappe) to $u = 0.496\sqrt{2gh}$* at the upper surface.

From what has been said it appears that the first of these two values is a little too great. The area of the curve between the extreme abscissæ, 0.112 and 0.760, which limit the curve of pressures, is 0.428. In other words, we have,

$$\int \left(\frac{u}{\sqrt{2gh}}\right) d\left(\frac{z}{h}\right) = \frac{1}{h\sqrt{2gh}} \int u\, d\, z = 0.428.$$

But the integral $\int u\, d z$ is no other than the discharge Q per

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* We must not forget that this value of u for the upper surface corresponds to the abscissa $z = 0.76\ h$, or, in other words, to a point situated a little down-stream from the vertical erected upon the crest. For the point situated upon the vertical we have $z = 0.78\ h$ and $u = 0.475\sqrt{2gh}$.

meter of length of the weir, whence $Q = 0.428\ h\ \sqrt{2gh}$. We thus find again nearly the same mean coefficient 0.427 given by the direct calibration for the six heads observed. This calculation is only approximate and should be subjected to certain corrections of secondary importance, notably by reason of the obliquity of the fluid filaments with reference to the orifice A. That orifice is, in fact, normal to the direction of their flow only when at the lower surface of the nappe. It becomes slightly oblique as the instrument is raised; but the reduction to be made in the velocities on that account would be very small,* and it would be useless to take account of them in the foregoing calculation, where we have in view only an approximate verification of the coefficient.

DIJON, December 23, 1889.

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* The mean direction of the liquid filaments at the upper surface of the nappe does not vary, in all of the six experiments, more than a small number of degrees from the normal to the plane of the orifice. The extreme variation, for the head 0.15 m. (5.9 inches), was about 13°. We have established by direct experiments that this obliquity has but very little influence upon the indications of the instrument.

PROFILES OF NAPPES.

Tables of the co-ordinates obtained by direct measurement.

(The millimeter is taken as unit.)

Profiles of Nappes.

Vertical weir 1.13 m. (3.7 feet) high. (See Series Nos. 1 and 2.)
Lower curve measured with descending point.

Abscissas.	Ordinates.								
	Expt. No. 1. Head 152	Expt. No. 2. Head 200	Expt. No. 3. Head 252	Expt. No. 4. Head 268	Expt. No. 5. Head 300	Expt. No. 6. Head 318	Expt. No. 7. Head 345	Expt. No. 8. Head 400	Expt. No. 9. Head 449
The origin of abscissas is 11 mm. from the crest for experiments 1 and 2; 10 mm. for experiments 3, 4 and 6; 9 mm. for experiments 5 and 7; 7 mm. for experiment 8, and 5 mm. for experiment 9.									
Crest.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0	. . .	11.1	. . .	11.8	. . .	15.8	14.1	10.5	15.7
10	13.4	15.8	17.7	19.2	19.7	20.6	21.3	21.0	23.5
20	. . .	19.7	. . .	24.1	. . .	26.8	26.6	28.6	31.2
30	16.4	21.6	25.1	27.0	28.7	28.2	31.4	34.1	37.7
40	. . .	22.3	. . .	28.2	. . .	30.8	33.5	36.3	41.8
50	14.3	20.6	28.2	28.9	30.0	33.7	36.7	38.8	44.6
60	. . .	20.9	. .	28.8	. . .	. . .	37.8	43.8	45.6
70	9.7	17.6	26.4	29.2	33.9	34.5	39.9	44.4	48.6
80	. . .	17.1	. . .	27.5	. .	. . .	41.3	44.7	49.8
90	0.4	13.3	23.1	28.4	30.8	36.0	41.0	45.6	49.6
100	. . .	11.3	. . .	24.5	. . .	. . .	38.3	46.4	49.2
110	— 11.0	. . .	20.0	21.0	30.5	29.4	. . .	46.0	50.4
120	. . .	5.1	. . .	19.8	. . .	. . .	35.7	44.1	49.8
130	— 20.2	. . .	12.1	16.5	23.3	27.0	. . .	45.2	50.7
140	. . .	— 7.1	. . .	13.5	. . .	. .	29.3	44.1	49.0
150	— 36.5	. . .	2.2	8.8	15 8	22.5	. . .	39.3	50.6
160	. . .	. . .	. . .	2.2	. .	. . .	. . .	. . .	47.1
170	— 53.4	— 23.9	— 4.6	3.3	13.4	17.1	20.9	35.8	44.8
180	. . .	. . .	. . .	— 4.8	. . .	. . .	. . .	. . .	41.9
190	. . .	. . .	. . .	— 4.4	. . .	8.8	. . .	27.2	. . .
200	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	34.2
210	. . .	. . .	. . .	. . .	. . .	— 1.7	. . .	22.4	. . .
220	— 114.0	— 63.8	— 32.2	— 24.1	— 15.9	. . .	— 1.0	. . .	31.9
230	. . .	. . .	. . .	. . .	. . .	— 8.9	. . .	19.6	. . .
240	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	23.6
250	. . .	. . .	. . .	. . .	. . .	— 25.7	. . .	7.6	. . .
260	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	14.8
270	— 181.7	. . .	— 71.4	— 57.6	— 44.3	— 41.3	— 22.5	. . .	. . .
280	. . .	. . .	. . .	. . .	. . .	. . .	. . .	— 7.1	8.8

Abscissas.	Ordinates.								
	Expt. No. 1. Head 152	Expt. No. 2. Head 200	Expt. No. 3. Head 252	Expt. No. 4. Head 268	Expt. No. 5. Head 300	Expt. No. 6. Head 318	Expt. No. 7. Head 345	Expt. No. 8. Head 400	Expt. No. 9. Head 449
300	. . .	. . .	. . .	. . .	. . .	— 57.3	. . .	. . .	— 0.9
310	. . .	. . .	. . .	. . .	. . .	. . .	. . .	— 22.8	. . .
320	— 249.1	. . .	— 117.4	— 106.7	— 87.3	. . .	— 64.6	. . .	— 10.8
330	. . .	. . .	. . .	. . .	. . .	— 88.3	. . .	. . .	. . .
350	. . .	. . .	. . .	. . .	. . .	. . .	. . .	— 49.0	— 32.4
370	— 355.5	. . .	— 180.5	— 160.3	— 134.0	— 117.9	— 99.5	. . .	. . .
380	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	— 53.2
390	. . .	. . .	. . .	. . .	. . .	. . .	. . .	— 79.4	. . .
420	— 460.1	. . .	— 249.1	— 218.7	— 185.5	— 171.9	— 146.8	. . .	— 78.4
430	. . .	. . .	. . .	. . .	. . .	. . .	. . .	— 110.4	. . .
470	. . .	. . .	— 315.5	— 283.4	— 243.7	— 223.3	— 197.4	— 147.4	— 113.8
510	. . .	. . .	. . .	. . .	. . .	. . .	. . .	— 190.4	. . .
520	. . .	. . .	— 398.1	. . .	— 325.1	— 294.3	— 262.5	. . .	— 162.4
550	. . .	. . .	. . .	. . .	. . .	. . .	. . .	— 227.8	. . .
570	. . .	. . .	. . .	. . .	. . .	— 365.3	— 316.6	. . .	. . .
600	. . .	. . .	. . .	. . .	. . .	. . .	. . .	— 289.5	. . .
620	. . .	. . .	. . .	. . .	. . .	— 450.8	. . .	. . .	. . .
650	. . .	. . .	. . .	. . .	. . .	. . .	. . .	— 348.0	. . .
670	. . .	. . .	. . .	. . .	. . .	— 529.6	. . .	. . .	. . .
700	. . .	. . .	. . .	. . .	. . .	. . .	. . .	— 409.4	. . .
720	. . .	. . .	. . .	. . .	. . .	— 619.3	. . .	. . .	. . .
750	. . .	. . .	. . .	. . .	. . .	. . .	. . .	— 486.4	. . .
770	. . .	. . .	. . .	. . .	. . .	— 716.3	. . .	. . .	. . .

Profiles of Nappes.

Vertical weir 1.13 m. (3.7 feet) high. (See Series Nos. 1 and 2.)
Lower curve measured with ascending point.

Abscissas.	Ordinates.								
	Expt. No. 1. Head 156	Expt. No. 2. Head 200	Expt. No. 3. Head 251	Expt. No. 4. Head 276	Expt. No. 5. Head 300	Expt. No. 6. Head 325	Expt. No. 7. Head 352	Expt. No. 8. Head 400	Expt. No. 9. Head 449
The origin of abscissas is 8 mm. from the crest for experiment 1; 7 mm. for experiments 2 and 3; 6 mm. for experiments 4, 5 and 6; 5 mm. for experiments 7 and 8, and 4 mm. for experiment 9.									
Crest.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0	9.2	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
1	. . .	8.2	11.6	. . .	. .	. . .	. . .	. . .	. .
2	. . .	. . .	. . .	12.2	10.9	12.8	. . .	. . .	. . .
3	. . .	. . .	. .	. . .	. . .	. .	14.2	13.0	. . .
4	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	14.7
10	13.5	15.1	17.7	19.4	17.4	19.9	20.4	21.7	19 6
20	15.9	19.0	22.0	23.8	23.5	25.5	28.0	26.2	25.7
30	17.8	21.2	26.5	26.7	27.0	30.1	32.3	31.9	32.8
40	17.0	23.2	26.4	29.7	30.8	32.8	34.6	36.3	37.2
50	15.9	21.8	28.8	31.3	31.8	34.0	35.9	39.5	40.2
60	14 3	21.2	27.7	32.2	32.7	35.9	37.9	40.3	44.5
70	10.9	19.6	28.4	31.8	33.4	36.7	37.8	41 4	45 9
80	7.5	18.8	27.7	31.5	31.9	35.2	39.9	43.8	47.7
90	4.8	14.8	26.4	30.3	32.1	35.7	39.7	43.9	48.6
100	— 0.6	10.8	23.1	27.4	31.9	35.3	39.7	44.3	49.0
110	— 6.0	. . .	20.5	27.3	. .	34.9	38.7	. .	48.7
120	— 10.7	4.6	17.6	23.7	25 4	31.7	35.7	44.7	49.2
130	. . .	. . .	13.7	. . .	.	. .	33.7	. . .	48.3
140	— 26.7	— 6.7	11.2	17.9	20.6	27.8	32.9	40.8	47.9
150	. .	. . .	6.5	. . .	. .	. . .	. . .	. . .	48.5
160	— 40.4	— 20.6	1.7	9.2	15.3	23.7	26.8	34.7	47.7
170	. . .	. . .	— 2.8	. . .	. . .	. . .	. . .	. . .	46.7
180	— 60.8	— 33.3	— 9.1	0.7	5.1	16.8	20.8	33.5	41.9
200	— 81.4	— 50.7	— 16.3	— 9.3	— 4.4	7.0	15.1	26.6	38.1
220	— 103.3	— 66.5	— 31.7	— 21.4	— 16.1	— 1.1	6.7	20.6	30.8
240	. .	— 82.0	— 45.1	— 33.3	— 25 4	— 10.5	— 3.3	11.8	24.7
260	. . .	. .	. . .	— 49.3	— 37.7	— 24.1	— 15.3	. .	18.6
270	— 169.6	. . .	— 71.6	. . .	. . .	. .	. .	— 5.2	. . .
280	. . .	. . .	. . .	— 65.8	— 54.7	— 38.0	— 27.0	. . .	11.0
300	. . .	. . .	. . .	— 84.0	— 66.7	— 47.8	— 38.6	— 19.0	— 2.5
320	. . .	. .	— 123.3	— 101.3	— 84.2	— 70.1	— 54.0	. . .	— 10.2
340	. . .	. . .	. . .	. . .	— 105.5	. . .	. . .	— 47.5	. . .
370	. . .	. .	— 181.0	— 149.6	. .	— 111.3	— 93.2	. . .	— 39.5
380	. .	. . .	. . .	. . .	. . .	. . .	. . .	— 73.0	. . .
420	. . .	. . .	. . .	— 215.0	. .	— 161.6	— 139.3	— 107.0	— 77.0
460	. . .	. . .	. . .	. . .	. . .	. . .	. . .	— 142.0	. .
470	. . .	. . .	. . .	. . .	. . .	. . .	. .	. .	— 118.3

Profiles of Nappes.

Vertical weir 1.13 m. (3.7 feet) high. (See Series Nos. 1 and 2.)
Upper curve.

Abscissas.	Ordinates.								
	Expt. No. 1. Head 152	Expt. No. 2. Head. 200	Expt. No. 3. Head 252	Expt. No. 4. Head 268	Expt. No. 5. Head 300	Expt. No. 6. Head 318	Expt. No. 7. Head 345	Expt. No. 8. Head 400	Expt. No. 9. Head 449
Down-stream from the crest.									
The origin of abscissas is 41 mm. from the crest for experiment 9; 48 mm. for experiments 5, 6 and 7; 50 mm. for experiment 1; 72 mm. for experiment 8; 96 mm. for experiment 4; 97 mm. for experiment 2, and 99 mm. for experiment 3.									
Crest.	128.9	169.2	213.5	227.0	252.7	270.8	293.3	344.7	382.9
0	113.7	135.6	200.8	198.3	242.6	259.0	281.8	324.4	372.4
50	88.4	. . .	182.8	. . .	224.4	240.7	265.9		358.4
100	55.4	71.6	157.8	147.6	204.8	219.9	245.7	287.5	339.6
150	7.5	. . .	128.8	. . .	179.0	195.8	221.5	.	322.2
200	— 50.7	— 32.4	89.4	73.6	146.1	165.6	194.0	236.0	297.2
250	— 122.4	. . .	46.2	. . .	107.6	130.0	159.3	.	270.1
300	— 209.7	— 176.4	0.0	— 29.9	63.5	86.1	123.4	167.1	241.8
350	— 328.1	. .	— 60 2	. .	12.6	40.9	82.9	. .	204.6
400	— 421.0	— 348.4	— 133.6	— 170.6	— 47.5	— 5.3	27.1	87.5	167.1
450	. . .	.	— 209.7		— 108.6	— 65.4	— 29.6	. . .	125.0
500	. . .	— 588.4	— 296.7	— 339.4	— 174.5	— 142.8	— 90.3	— 22.8	78.1
550	. . .	. . .	. . .	. . .	. . .	— 213.7	— 154.1	. . .	. .
600	. . .	. . .	. . .	— 523.4	. .	. . .	. . .	— 142.4	. . .
700	. . .	. . .	. . .	— 758.4	. . . .	. . .	. . .	— 292.9	. . .
Up-stream from the crest.									
The origin of abscissas is 50 mm. from the crest for experiment 1; 51 mm. for experiment 3; 52 mm. for experiments 5, 6 and 7; 59 mm. for experiment 9; 103 mm. for experiment 2; 104 mm. for experiment 4, and 128 mm. for experiment 8.									
Crest.	128.9	169.2	213.5	227.0	252.7	270.8	293.3	344.7	382.9
0	136.7	185.4	226.0	245.5	263.6	280.2	305.2	366.8	395.8
50	140.8	. . .	229.8	. . .	273.3	288.5	313.5	. . .	403.6
100	. . .	191.9	. . .	255.5	. . .	. .	. . .	377.0	411.0
150	147.0	. . .	240.7	. . .	281.3	300.8	322.9	. . .	413.9
200	. . .	196.1	. . .	260.1	.	. . .	. . .	383.9	422 2
250	149.8		244.0	. . .	288.2	306.1	330.7	. . .	425.0
300	. . .	196.7	. . .	261.9	. . .	. . .	. . .	388.6	431.1
350	148.6	. . .	248.3	. . .	292.7	311 0	334.4	. . .	. . .
400	. . .	199.8	. . .	264.1	. . .	. . .	. . .	391.6	433.8
450	150.9	. . .	248.3	.	294.6	313.2	340.3	. . .	. . .
500	. . .	198.0	. . .	266.0	.	. .	. .	393.8	436.2
550	151.4		249.7	. . .	296.3	314.0	340.1	. . .	. . .
600	. . .	199.4	. . .	266.9	. . .	. .	. . .	396.5	441.8
650	151.4	. .	251.2	. . .	296.6	316.7	341.8	. . .	. . .
700	. . .	198.2	. . .	267.0	. . .	. . .	.	395.4	445.6
750	152.8	. . .	250.7	. . .	298 0	318.0	343.0	. . .	. . .
800	. . .	199.2	. . .	268.8	. . .	. . .	. . .	400.0	446.0
850	154.1	. . .	252.1		297.6	318.8	344.0	. . .	. . .
900	. . .	199.9	. . .	268.4	. .	. . .	. . .	398.7	445.6
950	154.8	. . .	252.8	. .	299.1	317.8	345.0	. . .	. . .
1,000	. . .	199.8	. . .	268.0	. .	.	. . .	400.1	447.5
1,050	153.8	. . .	252.8	. . .	299.5	319.0	346.2	.	. . .
1,100	. . .	200.3	. . .	268.2	. . .	. . .	. . .	401.2	449.2

Profiles of Nappes.

Vertical weir 0.35 m. (1.15 feet) high. (See Series Nos. 8 and 9).
Lower curve.

Abscissas.	Ordinates.							
	Expt. No. 1. Head 122	Expt. No. 2. Head 152	Expt. No. 3. Head 202	Expt. No. 4. Head 250	Expt. No. 5. Head 301	Expt. No. 6. Head 353	Expt. No. 7. Head 405	Expt. No. 8. Head 450
The origin of abscissas is 10 mm. from the crest for experiments 3 and 8; 9 mm. for experiments 1, 2 and 4; 8 mm. for experiments 5 and 6, and 7 mm. for experiment 7.								
Crest.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0	7.5	7.8	10.3	11.8	11.2	9.9	13.1	11.5
10	10.3	13.4	15.1	17.4	18.4	18.1	20.2	20.5
20	12.2	14.4	18.3	22.7	22.1	24.9	25.3	. . . .
30	11.6	15.5	21.0	22.7	24.3	28.1	28.3	31.8
40	9.7	15.0	19.9	23.4	27.3	30.4	33.4	. .
50	7.2	13.8	19.5	24.0	28.3	35.2	35.3	36.9
60	3.6	11.8	19.6	24.6	30.1	32.2	. . . .	. . . .
70	0.0	8.4	17.5	25.1	30.2	34.0	37.3	40.0
80	— 4.8	2.3	15.1	25.1	29.0	34.1	. . . .	. . . .
90	. . . .	— 1.1	10.5	21.2	30.0	32.3	40.5	42.9
100	— 16.7	— 4.8	9.3	17.5	25.2	34.1	. . . .	. . . .
110	. . . .	. . . .	. . . .	17.0	25.5	32.2	39.6	43.9
120	— 33.6	— 19.6	0.6	14.1	22.3	29.1	. . . .	. . . .
130	. . . .	. . . .	. . . .	8.3	20.3	30.2	38.5	41.2
140	— 55.1	— 32.2	— 10.2	. . . .	. . . .	. . . .	. . . .	. . . .
150	. . . .	. . . .	. . . .	1.8	13.2	23.8	30.5	41.5
170	— 84.1	— 57.2	— 28.3	— 7.6	4.8	19.9	29.1	36.9
190	. . . .	. . . .	. . . .	— 20.0	— 1.8	. . . .	21.2	. . .
200	. . . .	— 88.4	. . . .	. . . .	. . . .	10.4	. . . .	32.4
210	. . . .	. . . .	. . . .	. . . .	. . . .	. . . .	16.2	. . . .
220	— 160.7	. . .	— 73.6	— 39.0	— 20.8	. . . .	. . .	. . .
230	. . . .	— 125.8	. . . .	. . . .	. . . .	— 6.6	10.0	20.8
250	. . . .	. .	. . . .	. . . .	. . . .	. . . .	0.0	. . . .
270	— 246.1	— 184.8	— 116.7	— 80.9	— 52.5	— 18.9	— 9.5	6.6
300	. . .	. . . .	. . . .	. . . .	. . . .	. . . .	— 20.8	. . . .
320	— 344.4	— 265.6	. . . .	— 131.2	— 90.8	— 58.6	. . . .	— 17.5
330	. . . .	. . . .	. . . .	. . . .	. . . .	. . . .	— 40.7	. . . .
370	— 457.1	— 360.6	— 254.7	— 177.4	— 130.8	— 93.4	— 62.0	— 41.1
420	. . . .	. . . .	. . . .	. . . .	. . . .	— 138.9	— 98.8	— 77.2
470	. . . .	— 589.8	. . . .	— 320.9	— 244.3	— 185.2	— 137.9	— 119.0
520	. . . .	. . . .	. . . .	. . . .	. . . .	. . .	— 190.7	— 157.5
570	. . . .	. . . .	. . . .	— 490.9	— 372.8	— 299.4	— 238.4	— 197.2
620	. . . .	. . . .	. . . .	. . . .	. . . .	. . . .	— 307.7	— 249.0
660	. . . .	. . . .	. . . .	. . . .	. . .	. . . .	. . . .	— 310.1

Profiles of Nappes.

Vertical weir 0.35 m. (1.15 feet) high. (See Series Nos. 8 and 9.)
Upper curve.

Abscissas.	Ordinates.							
	Expt. No. 1. Head 122	Expt. No. 2. Head 152	Expt. No. 3. Head 202	Expt.* No. 4. Head 250	Expt. No. 5. Head 301	Expt. No. 6. Head 353	Expt. No. 7. Head 405	Expt. No. 8. Head 450
Down-stream from the crest.								
The origin of abscissas is 29 mm. from the crest for experiments 1 and 2; 77 mm. for experiment 7; 78 mm. for experiment 5; 95 mm. for experiment 8; 98 mm. for experiment 6; 99 mm. for experiment 4, and 100 mm. for experiment 3.								
Crest.	103.7	129.6	170.1	214.1	257.4	304.0	350.3	390.8
0	93.7	121.6	141.0	182.5	235.7	276.5	327.6	361.2
50	75.1	103.0	. . . .	. . . .	. . . .	. . . .	. . . .	. . . .
100	38.2	76.2	75.9	125.1	196.5	235.8	291.1	328.3
150	— 15.8	29.7	. . . .	. . . .	. . . .	. . . .	. . . .	. . . .
200	— 80.8	. . . .	— 26.6	67.3	126.2	174.2	243.9	276.7
250	— 166.8	— 86.8	. . . .	. . . .	. . . .	. . . .	. . . .	. . . .
300	. . . .	. . . .	— 147.9	— 35.9	38.2	113.1	175.3	218.3
350	— 396.1	— 268.1	. . . .	. . . .	. . . .	. . . .	. . . .	. . . .
400	. . . .	. . . .	— 342.4	— 165.8	— 62.2	22.0	95.9	141.9
450	. . . .	— 503.8	. . . .	. . . .	. . . .	. . . .	. . . .	. . . .
500	. . . .	. . . .	— 576.9	— 350.9	— 218.7	— 96.0	0.5	49.1
600	. . . .	. . . .	. . . .	. . . .	— 368.9	. . . .	— 121.3	— 63.9
Up-stream from the crest.								
The origin of abscissas is 21 mm. from the crest for experiments 1 and 2; 100 mm. for experiment 3; 101 mm. for experiment 4; 102 mm. for experiment 6; 105 mm. for experiment 8; 122 mm. for experiment 5, and 123 mm. for experiment 7.								
Crest.	103.7	129.6	170.1	214.1	257.4	304.0	350.3	390.8
0	107.2	133.2	187.3	229.3	278.0	318.9	372.8	406.0
50	111.7	141.9	. . . .	. . . .	. . . .	. . . .	. . . .	. . . .
100	116.1	144.5	195.7	237.7	286.8	331.6	383.3	417.7
200	120.6	147.6	199.1	242.1	290.6	339.1	390.5	430.7
300	121.2	148.8	199.3	244.4	294.2	344.0	393.1	438.8
400	121.2	149.2	200.4	248.1	300.3	346.1	396.5	436.9
500	120.9	150.6	200.4	248.1	298.7	348.4	397.7	440.7
600	121.1	149.7	197.5	251.1	298.0	350.1	398.7	441.4
700	123.0	152.2	199.6	250.1	300.0	349.3	400.2	447.1
800	123.2	152.7	200.7	247.8	301.7	349.7	403.4	445.3
900	122.0	150.6	198.5	249.0	301.7	352.9	401.4	448.1
1,000	122.4	151.8	198.0	249.5	299.8	351.1	403.0	447.8
1,100	122.2	152.2	. . . .	. . . .	. . . .	. . . .	. . . .	. . . .

* The four points under Experiment No. 4, given as 200, 300, 400 and 500 mm. from the origin 0, were actually 180, 280, 380 and 480 mm. from the origin, respectively.

Profiles of Nappes.

Weir 1.13 m. (3.7 feet) high, inclined 45° up-stream. (See Series No. 11)

Abscissas.	Ordinates.				
	Expt. No. 1. Head 298	Expt. No. 2. Head 339	Expt. No. 3. Head 378	Expt. No. 4. Head 416	Expt. No. 5. Head 449
	Lower Curve.				
The origin of abscissas is 11 mm. from the crest for experiments 1 and 3, and 10 mm. for experiments 2, 4 and 5.					
Crest.	13.1	12.2	16.2	14.1	18.2
0	27.9	30.4	35.4	32.9	33.5
10	33.3	39.5	38.9	40.5	43.3
20	39.6	42.5	45.2	45.8	46.9
30	43.8	45.4	47.0	52.4	60.4
40	47.2	50.3	52.5	58.3	62.0
50	46.5	50.1	54.4	59.1	63.9
60	49.4	51.4	61.3	64.9	69.2
70	49.8	52.1	63.0	67.1	67.6
80	48 3	53.9	59.9	65.9	69.9
90	45.5	51.8	58.9	66.9	72.4
100	43.2	53.7	59.3	65.3	68.4
110	42.2	49.7	59.0	64.4	69.5
120	40.8	47.1	56.3	64.6	70.2
130	37.7	46.1	57.3	64.3	67.6
140	36.2	44.8	55.5	62.8	67.0
150	32.2	44.6	51.1	59.2	68.4
160	31.0	39.0	47.6	57.5	66.3
170	19.6	36.1	47.5	56.6	64.3
180	17.1	31.3	44.3	56.1	64.1
190	13.3	24.4	39.9	50.4	59.2
200	13.2	21.3	34.6	47.6	53.0
210	3.3	18.3	33.7	45.0	49.3
220	— 0.7	11.2	29.6	38.0	47.5
230	— 5.9	8.7	23.5	32.5	44.4
240	— 16.5	0.8	19.0	27.5	44.1
250	— 21.5	— 5.4	15.0	23.3	40.5
260	— 31.1	. . . .	6.5	23.3	33.9
270	— 32.5	— 19.6	— 3.5	17 2	23.0
280	— 46.3	. . . .	— 5.0	14.0	20.9
290	— 53.0	— 35.5	— 7.6	1.7	19.5
300	. . .	. .	. . . .	1.0	15.1
310	— 73.0	— 42.1	— 27.8	— 2.2	7.2
320	. . . .	. . . .	. . . .	— 17.6	6.9
330	— 87.2	— 61.0	— 38.8	— 23.2	— 3.6
340	. . . .	. . .	. . . .	— 27.9	. . .
350	— 103.0	— 87.6	— 56.6	. . . .	— 14.8
360	. . .	. . . .	. . . .	— 39.4	. . . .
370	— 128.4	— 95.2	— 72.8	. . . .	— 25.2
380	. . . .	. . . .	. . . .	— 52.9	. . . .
390	— 160.1	— 124.7	— 87.1	. . .	— 39.4
400	. . . .	. . .	. . .	— 77.9	. . . .
410	. . .	— 146.1	— 101.8	. . . .	— 56.7
420	— 191.5	. . . .	. . . .	— 89.3	. . . .
430	. . . .	— 163.6	. . . .	. . . .	. . . .
440	. . . .	. . . .	— 140.6	— 103.7	— 77.3
450	— 231.1	. . . .	. . . .	. . . .	. . . .
460	. . . .	— 203.1	. . . .	. . . .	. . . .
470	. . . .	. . . .	— 159.6	— 136.2	— 109.3

Abscissas.	Ordinates. Expt. No. 1. Head 298	Expt. No. 2. Head 339	Expt. No. 3. Head 378	Expt. No. 4. Head 416	Expt. No. 5. Head 449
490	. . . .	— 226.6	. . . .	. . . .	. . . .
500	. . .	. .	— 201.3	— 160.3	— 134.4
520	. . . .	— 276.7	. . .	. . .	. . . .
530	. . . .	. . . .	. . .	— 198.3	. . . .
540	. . . .	. . .	— 248.9	. . . .	— 165.6
550	. . .	— 312.6	. .	.	. . . .
570	. . . .	. . . .	. . .	— 246.8	. . . .
590	. . . .	. . . .	— 317.8	. .	— 230.0
610	. . .	. . . .	. . .	— 292.9	. . . .
640	. . . .	. . . .	. . . .	. . . .	— 292.8
650	. . . .	. . . .	. . . .	— 341 4	. . . .
690	. . . .	. . . .	. . . .	. . . .	— 344.0

Upper curve, down-stream from the crest.

The origin of abscissas is 16 mm. from the crest for experiment 1; 15 mm. for experiments 3, 4 and 5, and 14 mm. for experiment 2.

Crest.	261.8	294.3	330.2	361.0	389.9
0	256.6	289.8	321.9	363.9	384 0
50	241.6	275.9	309.9	344.0	370 6
100	222.6	259.0	292.7	328 4	354.7
150	197.4	239.6	273.4	309.0	339.0
200	167.9	213.0	247.1	284.5	316.0
250	134.7	180.1	218.3	257.3	287.5
300	88.7	142.2	183.4	224.5	258.2
350	50.3	98.7	146.3	193 5	225.7
400	— 15.1	52.5	100.5	148.8	190.8
450	— 78.9	— 10.6	52.0	106.4	149.9
500	. . .	— 66.6	— 3.4	59.5	99.7
550	. . . .	— 135.7	— 61.1	4.3	49.0
600	. . . .	. . . .	— 129.8	— 64.7	2.6
650	. . . .	. . . .	. . . .	— 121.5	— 67.6
700	. . . .	. . . .	. . . .	. . . .	— 129.3

Upper curve, up-stream from the crest.

The origin of abscissas is 34 mm. from the crest for experiment 1; 35 mm. for experiments 3, 4 and 5, and 36 mm. for experiment 2.

Crest.	261.8	294.3	330.2	361.0	389.9
0	266.1	303.2	337.1	367.8	396.4
50	275.2	310.3	343.7	376.7	404.5
100	280.9	317.8	350.2	383.2	410.2
150	284.6	319.6	355.2	391.6	417.9
200	288.9	327.0	358.2	395 4	424.6
250	290.4	329.1	363.5	397.9	427.3
300	294.6	331.3	367.4	400.9	429.4
350	295.0	333.3	369.1	404.9	434.9
400	296.9	337.5	369.4	404.4	438.9
450	298.5	335.1	371.5	408.7	438.3
550	295.8	337.5	373.8	410.6	442 0
650	298.7	338.2	376.0	412.5	444.0
750	300.0	339.5	376.4	411.8	447.6
850	299.7	338.4	377.0	416.0	446.5
950	300.6	340.0	378.7	415.3	447.0
1,050	299.2	341.0	378.6	415.8	447.0
1,150	299.0	339.1	379.4	417.4	448 0
1,250	300.6	341.2	378.5	416.5	448.8

Profiles of Nappes.

Weir 1.13 m. (3.7 feet) high, inclined 3 : 2 up-stream. (See Series No. 12).

Abscissas.	Ordinates. Expt. No. 1. Head. 200	Expt. No. 2. Head 250	Expt. No. 3. Head 300	Expt. No. 4. Head 357	Expt. No. 5. Head 400	Expt. No. 6. Head 456
	Lower curve.					
The origin of abscissas is 11 mm. from the crest for experiments 1 and 2, and 10 mm. for experiments 3 to 6.						
Crest.	9.4	11.0	12.2	12.6	14.8	. . .
0	21.7	25.8	21.9	25.9	28.5	30.7
10	24.6	30.8	30.6	33.9	36.4	37.3
20	28.4	33.1	35.3	39.2	41.7	45 6
30	30.7	35.9	38.9	42.4	47.4	50.3
40	33.0	36.9	43.4	47.6	51.8	53.4
50	33.6	39.4	43.3	49.4	48.9	54.8
60	33.2	37.6	45.5	50.6	52.7	59.7
70	30.4	40.5	45.9	50.5	54.0	62.7
80	26.8	37.2	45.5	53.1	56.0	67.4
90	23.6	34.8	45.6	51.7	58.5	67.4
100	20.9	33.7	42.0	49.5	57.8	66.8
110	15.4	29.2	44.1	49.4	59.0	65.8
120	10.3	26 3	42.0	51.0	59.5	68.0
130	5.5	22.7	35.7	48.0	57.1	64 5
140	— 1.2	. .	31.7	45.1	56.2	61.9
150	— 4.2	11.9	29.3	43.4	50.4	60.5
160	— 8.1	. . .	. . .	. .	. . .	61.2
170	— 22.2	6.8	22.2	38.3	46.8	58.9
180	— 27.6	. . .	. . .	. . .	. . .	62.9
190	. . .	— 8.6	11.0	33.7	38.5	. . .
200	— 46.5	. . .	. . .	. . .	. . .	49.6
210	. . .	— 21.6	0.8	22.5	36.9	. . .
220	— 61.7	. . .	. . .	. . .	. . .	47.0
230	. . .	— 35.1	— 11.6	12.3	27.3	. . .
240	— 79.8		. . .	. . .	. . .	42.1
250	. . .	— 53.9	— 24.4	1.5	18.6	. . .
260	— 104.2	. .	. . .	. . .	. .	34 3
270	.	— 73.3	— 36.8	— 7.7	4.0	. . .
280	— 124.1	. . .	.	. .	. . .	19.0
290	. . .	— 95.8	. . .	— 21.9	— 5.4	. . .
300	. . .	. .	— 63.3		. . .	12 6
310	— 169.5	— 117.5	. . .	— 35.7	— 18.9	. . .
320	. . .	. .	. . .	. . .	. .	0.5
330	. . .	— 141.6	— 85.1	— 53.4	— 27.2	. . .
340	— 223.1	. . .	. . .	. . .	. . .	— 9.8
350	. . .	. . .	. . .	. .	— 41.4	. . .
360	. . .	— 179.7	— 124.0	— 71.7	. . .	— 20.1
380	— 279.2	. . .	.		— 60.4	. . .
390	. . .	— 215.4	— 150.8	— 106.3	. . .	— 43.7
410	. . .	. . .	. . .	. .	— 91.7	. . .
420	. . .	— 249.0	— 189.3	— 134.1	. .	— 86.3
430	— 361.2	. . .	. . .	. . .	.	. . .
440	. . .	. . .	. . .	. . .	— 121.5	. .
450	. . .	— 299.7	— 227.5	— 163.6	. . .	— 85.8
470	. .	. . .	. .	. . .	— 150.5	. . .
480	— 472.2	. . .	. . .	. . .	. . .	— 113.3

Abscissas.	Ordinates.					
	Expt. No. 1. Head 200	Expt. No. 2. Head 250	Expt. No. 3. Head 300	Expt. No. 4. Head 357	Expt. No. 5. Head 400	Expt. No. 6. Head 456
490	. . .	— 375.2	— 276.8	— 206.1	.	. .
510	. . .	. . .	. . .	.	— 193.6	— 150.4
530	. . .	— 455.2	— 327.8	— 250.8	. . .	
540	. . .	. . .	. . .	. . .	. . .	— 170.6
550	. . .	. . .	. . .	. .	— 233.4	. . .
570	. . .	. . .	. .	— 310.0	. . .	. .
580	. . .	. . .	— 419.1	. . .	. . .	— 210.0
590	. . .	. . .	. . .	. . .	— 280.4	.
610	. . .	. . .	. .	— 363 3	. . .	. . .
630	. . .	. . .	. . .	. .	— 331.9	— 258.2
650	. . .	. . .	. . .	— 433.5	. . .	. . .
680	. . .	. . .	. . .	. .	— 410.4	— 324.4
690	. . .	. . .	. . .	— 492.8	. . .	. . .
730	. . .	. . .	. . .	— 559.8	— 492.4	— 400.7

Upper curve, down-stream from the crest.

The origin of abscissas is 54 mm. from the crest for experiments 1 and 2, and 53 mm. for experiments 3 to 6.

Crest.	174.6	215.4	259.5	308.8	344.9	390.9
0	158.5	202.9	244.3	292.0	332.8	379.2
50	134.3	183.0	227.4	277.5	317.0	362.4
100	105.9	159.0	201.2	255.5	296.5	344.3
150	69.3	126.8	179.1	232.4	275.3	325.3
200	23.8	88.4	146.4	203.7	248.7	300.3
250	— 41.2	40.0	104.3	170.6	216.3	274.1
300	— 107.8	— 20.8	61.1	133.7	184.6	242.8
350	— 190.6	— 84.7	2.9	84.7	138.1	203.6
400	— 291.0	— 153.7	— 52.4	36.5	100.3	164.9
450	— 386.0	— 242.0	— 118.3	— 17.0	46.1	120.3
500	— 502.0	— 334.0	— 197.0	— 82.5	— 12.7	75.4
550	. . .	— 425.0	— 273.0	— 148.1	— 64.0	19.5
600	. . .	— 540.0	. . .	— 224.0	— 137.0	— 37.0
650	. . .	— 666.0	. . .	— 307.3	— 200.0	— 105.0
750	. . .	. . .	. . .	— 394.8	— 290.0	— 170.0

Upper curve, up-stream from the crest.

The origin of abscissas is 46 mm. from the crest for experiments 1 and 2, and 47 mm. for experiments 3 to 6.

Crest.	174.6	215.4	259.5	308.8	344.9	390.9
0	181.9	225.5	266.3	317.5	353.1	401.8
50	187.6	234.9	276.9	325.7	361.8	411.1
100	193.2	235.5	280.3	329.7	370.2	419.1
150	195.2	241.6	288.0	336.7	377.4	422.6
200	196.9	243.9	289.5	342 9	381.2	428.2
300	199.1	248.1	295.7	347.4	387.0	437.3
400	199.9	250.8	296.3	351.4	388.4	443.1
500	200.8	249.8	301.0	351.7	394.1	446.2
600	202.7	253.0	300.1	354.8	397.7	448.0
700	202.2	252.6	301.0	354 7	398.9	451.2
800	201.9	252.3	300.8	355.7	399.9	455.5
900	201.2	253.4	299.1	358.2	400.0	453.0
1,000	202.2	252.2	301.2	360.4	400.2	455.1
1,100	202.5	252.0	301.6	357.7	401.6	455.9
1,200	202.7	251.9	302.1	358.7	400.8	457.1

Profiles of Nappes.

Weir 1.13 m. (3.7 feet) high, inclined 3 : 1 up-stream. (See Series No. 13.)

Abscissas.	Ordinates.					
	Expt. No. 1. Head 200	Expt. No. 2. Head 254	Expt. No. 3. Head 299	Expt. No. 4. Head 352	Expt. No. 5. Head 403	Expt. No. 6. Head 442
	Lower Curve.					
The origin of abscissas is 10 mm. from the crest for experiment 1; 9.5 mm. for experiments 2 and 5, and 9 mm. for experiments 3, 4 and 6.						
Crest.	0.0	0.0	0.0	0.0	0.0	0.0
0	17.3	19.5	20.0	20.5	22.5	22.1
10	22 1	29.7	27.2	31.6	34.4	30.8
20	25.5	28 8	32.5	38.5	37.5	39.9
30	26.7	34.1	35.2	41.4	44.9	46.9
40	28.3	33.9	38.5	45.8	47.9	49.8
50	27.5	34.5	40.6	47.7	51.5	53.0
60	26.5	33.8	42.0	47.0	54.1	55.0
70	25.4	33.0	41.1	50.8	53.8	56.8
80	23 6	34.2	40.6	50.5	52 8	57.6
90	20.4	31.5	39.0	48.7	54.4	59.2
100	17.3	28.3	40.1	47.1	52.9	60.6
110	14.3	27.5	38.1	47.1	53.7	60.6
120	8.9	21.7	35.2	42.5	53.7	59.5
130	6.6	21.9	31.3	45.1	52.6	59.6
140	— 2.0	19.1	30.4	43.5	52.4	58.3
150	. . .	11.8	25.4	39.8	50.0	58.8
160	— 11.7	6.8	20.6	37.7	46.2	53.8
170	. . .	6.3	17.2	36.1	44.3	55.1
180	— 26.9	— 1.9	14.1	29.1	43.0	52.2
190	. .	— 8.3	5.8	28.1	37.8	45.9
200	— 41.2	. . .	. . .	24.6	. . .	. . .
210	. . .	— 23.1	2.4	15.4	34.3	41.2
220	— 59.7	. . .	. . .	. . .	. . .	. . .
230	. .	— 33.0	— 13.2	7.0	28.3	34.1
240	— 70.4	. . .	. . .	. . .	. . .	. . .
250	. . .	— 53 5	— 26.4	— 7.0	17.4	22.6
270	— 109.1	— 63.2	— 41.5	— 13.4	8.8	19.4
290	. . .	. .	— 53.8	— 26.2	— 3.3	8.8
300	— 153.8	— 100.4	. . .	. . .	.	. .
310	. . .	. . .	. .	— 37.9	— 16.0	0.6
320	. . .	. . .	— 81.8	. . .	. . .	. . .
330	— 194.3	— 130.6	. . .	— 55.2	— 26.4	— 10.3
350	. . .	. .	— 107.3	. .	— 41.3	— 23.5
360	. . .	— 165.3	. . .	— 82.6	. . .	. . .
370	— 247.7	. . .	. . .	. . .	— 57.6	— 34.7
390	. . .	— 209.2	— 155.0	— 101.5	.	— 48.2
400	. .	. . .	. . .	. . .	— 83.3	. . .
410	— 328.1	. .	. . .	. .	. . .	. . .
420	. . .	. . .	. . .	— 134.7	. . .	— 76.2
430	. . .	— 265.9	— 199.5	. . .	— 105.8	. . .
450	— 394.0	. . .	. . .	. . .	. . .	— 97.4
460	. . .	. . .	. . .	— 181.0	— 134.1	. . .
470	. . .	— 321.5	— 246.9	. . .	. . .	. . .
480	. . .	. . .	. . .	. . .	. .	— 122.4
490	— 474.7	. . .	. . .	. . .	— 165.0	. . .

Abscissas.	Ordinates.					
	Expt. No. 1. Head 200	Expt. No. 2. Head 254	Expt. No. 3. Head 299	Expt. No. 4. Head 352	Expt. No. 5. Head 403	Expt. No. 6. Head 442
500	. . .	. . .	. . .	— 215.2	. . .	. . .
510	. . .	— 383.2	— 307.7	. . .	. . .	— 149.5
530	. . .	. . .	. . .		— 201.2	. . .
540	— 580.9	. . .	. . .	— 269.2	. . .	— 181.0
550	. . .	— 455.1	— 367.8	. . .	. . .	. . .
570	. . .	. . .	. . .	. . .	— 249.9	— 208.5
590	— 708.7	. . .	— 422.2	— 341.6	. . .	. . .
600	. . .	. . .	. . .	. . .	. . .	— 236.3
610	. . .	. . .	. . .	. . .	— 300.8	. . .
640	. . .	. . .	. . .	— 420.4		— 296.2
650	. . .	. . .	. . .	. . .	— 336.0	. . .
690	. . .	. . .	. . .	. . .	— 397.8	— 355.2

Upper curve, down-stream from the crest.

The origin of abscissas is 16 mm. from the crest for experiment 1, and 15 mm. for experiments 2 to 6.

Crest.	172 0	221.1	257.8	304.8	346.6	381.7
0	165.6	215.3	255.3	300.6	344.9	377.4
50	152.7	200.5	239.7	285.2	333.1	365.2
100	130.0	180.1	224.7	268.1	315.8	349.0
150	96.7	154.2	201.2	247.8	296.2	328.7
200	57.1	119.9	171.6	221.2	271.2	309.0
250	11.0	80.4	137.2	195.0	245.8	281.1
300	— 57.5	32.9	97.1	157.1	215.0	254.5
350	— 122.0	— 23.1	48.1	116.1	175.1	224.6
400	— 204.1	— 88.0	— 6.4	72.2	135.4	182.5
450	— 298.7	— 156.7	— 64.6	20.1	95.3	142.8
500	— 411.1	— 235.5	— 142.9	— 40.9	43.8	98.9
550	— 515.6	— 334.8	— 214.8	— 104.7	— 11.8	43.3
600	— 646.5	— 423.5	— 299.6	— 178.4	— 73.1	— 8.8
650	. . .	. . .	— 383.6	— 250.4	— 130.7	— 65.6
700	. . .	. . .	— 475.8	— 336.3	— 214.5	— 127.6

Upper curve, up-stream from the crest.

The origin of abscissas is 34 mm. from the crest for experiment 1, and 35 mm. for experiments 2 to 6.

Crest.	172.0	221.1	257.8	304.8	346.6	381.7
0	177.2	226.6	266.8	309.5	353.2	386.9
50	185.0	233.3	275.1	319.8	363.2	395.4
100	192.4	239.1	279.5	326.3	372.3	405.6
150	194.9	241.8	285.8	331.4	376.8	412.1
250	196.8	249.7	289.9	337.8	385.0	421.9
350	194.0	251.4	293.8	343.2	390.5	428.9
450	198.0	251.5	296.8	347.3	395.8	432.0
550	199.8	254.4	297.6	349.7	398.6	435.3
650	200.5	254.2	298.3	350.9	400.8	438.0
750	202.7	253.5	301.0	352.7	402.2	441.5
850	202.4	254.9	302.0	352.2	401.5	439.5
950	199.0	254.5	301.7	351.8	403.3	441.4
1,050	200.6	255.9	301.6	354.0	403.5	441.5
1,150	200.2	253.4	302.3	352.4	405.1	442.0
1,250	201.8	255.0	301.8	352.7	405.2	443.5

Profiles of Nappes.

Weir 1.13 m. (3.7 feet) high, inclined 3 : 1 down-stream. (See Series No. 14.)

Abscissas.	Ordinates.					
	Expt. No. 1. Head 203	Expt. No. 2. Head 250	Expt. No. 3. Head 299	Expt. No. 4. Head 350	Expt. No. 5. Head 398	Expt. No. 6. Head 447
	Lower Curve.					
The origin of abscissas is 10 mm. from the crest for experiments 1, 2, 3, 4 and 6, and 9 mm. for experiment 5.						
Crest.	0.0	0.0	0.0	0.0	0.0	0 0
0	8.2	10.8	10.2	10.9	11.2	12.0
10	12.7	14.9	16.9	16.6	18.1	18.2
20	15.4	18.5	21.4	20.9	21.7	23.1
30	16.9	20.8	23.2	24.2	26.8	29.4
40	16.4	22.6	25.6	27.7	30.1	32.0
50	15.9	23.1	26.8	29.8	31.2	36.2
60	15.4	21.8	27.3	29.9	32.5	39.2
70	12.6	20.7	26.1	30.7	38.0	40.9
80	10.0	18.8	25.2	30.3	35.9	41.4
90	7.0	17.8	24.3	29.0	35.6	40.8
100	4.7	12.8	22.6	28.3	35.2	40.1
110	0.6	11.5	19.1	27.5	35.0	39.9
120	— 3.8	10.4	17.9	26.1	33.6	39.2
130	. .	4.8	16 5	24.8	31.3	37.2
140	— 13.4	1.0	12.7	23.2	31.2	. . .
150	. . .	— 3.0	9.6	18.9	30.4	34.8
160	— 25.7	. . .	4.5	16.6	25 8	. . .
170	. .	— 15.7	2.5	13.2	23.7	30.3
180	— 41.3	. . .	— 3.5	9.5	19.5	. . .
190	.	— 24.8	— 7.0	4.4	18.6	25.9
200	— 55.4	. . .	. . .	2.9	13.8	. . .
210	.	— 37.9	— 19.0	— 1.4	. .	23.1
220	. . .	. . .	. . .	— 6.7	7.6	. . .
230	— 78.8	— 52.4	— 29.4	— 11.8	. . .	11.6
240	. .	. . .	. . .	. . .	— 0.2	. . .
250	. . .	— 63.4	— 42.8	— 20.9	. . .	5.3
260	— 104.3	. . .	. . .	. . .	— 11.9	. . .
270	. . .	— 81.4	— 54.4	— 32.4	. .	— 3.3
290	— 140.3	. . .	. . .	— 41.9	— 26.1	— 12.9
300	. . .	— 113.1	— 82.3	. .	. . .	. . .
310	. . .	. . .	. . .	— 59.2	. . .	. . .
320	. . .	. . .	. . .	.	— 44.9	— 25.5
330	— 197.0	— 139.0	— 107.6	— 77.5	. . .	. . .
350	. . .	. . .	. .	. .	— 62.6	— 36.4
360	. . .	— 179.4	— 129.3	— 98.2	. . .	. . .
370	— 259.2	. . .	. . .	. . .	. . .	. . .
380	. .	. . .	. . .	. . .	. .	— 62.8
390	. . .	— 215.8	. . .	— 118.4	— 93.6	. . .
400	. . .	. . .	— 174.1	. . .	. . .	. . .
410	— 314.2	. . .	. . .	. . .	. . .	— 84.0
420	. . .	. . .	. . .	— 156.3	. . .	. . .
430	. . .	— 273.1	. . .	. . .	. . .	. . .
440	. . .	. . .	— 219.0	. . .	— 133.2	. . .
450	— 374.8	. . .	. . .	— 182.2	. .	— 116.9
470	. . .	— 332.8	. . .	. . .	. . .	. . .

Abscissas.	Ordinates.					
	Expt. No. 1. Head 203	Expt. No. 2. Head 250	Expt. No. 3. Head 299	Expt. No. 4. Head 350	Expt. No. 5. Head 398	Expt. No. 6. Head 447
480	. . .	. . .	. . .	— 220.8	. . .	. . .
490	— 468.9	. . .	— 272.8	. . .	— 183.7	— 151.0
510	. . .	. . .	. . .	— 247.4	. . .	. . .
520	. . .	— 415.8	. . .	. . .	. . .	. . .
530	. . .	. . .	. . .	. . .	. . .	— 188.1
540	— 571.8	. . .	. . .	. . .	— 235.6	. . .
550	. . .	. . .	. . .	— 296.8	. . .	. . .
570	. . .	— 493.4	. . .	. . .	. . .	. . .
590	— 697.5	. . .	— 429.0	— 350.5	— 301.7	— 250.8
640	— 826.3	. . .	. . .	. . .	. . .	. . .
650	. . .	. . .	. . .	. . .	. . .	— 307.8
690	. . .	. . .	. . .	. . .	— 426.7	. . .

Upper curve, down-stream from the crest.

The origin of abscissas is 16 mm. from the crest for experiments 1, 2, 3, 4 and 6, and 15 mm. for experiment 5.

Crest.	169.6	206.8	248.4	289.8	334.8	373.7
0	164.1	203.4	244.7	288.8	330.0	372.5
50	147.8	188.9	231.3	274.9	318.1	356.8
100	124.0	166.5	212.2	255.2	299.2	341.5
150	94.3	141.3	187.5	234.2	280.6	321.2
200	56.8	107.9	159.7	208.9	256.3	299.6
250	9.1	67.3	125.5	179.9	228.1	273.5
300	— 46.8	20.3	88.2	147.9	199.0	247.7
350	— 112.7	— 32.6	38.5	109.1	163.7	211.0
400	— 193.2	— 99.3	— 11.0	58.9	121.1	177.4
450	— 300.2	— 171.6	— 68.8	8.5	74.4	136.3
500	— 380.1	— 253.2	— 134.6	— 52.1	25.0	92.4
550	— 493.2	— 331.7	— 212.2	— 107.3	— 27.9	48.4
600	— 604.2	— 432.6	— 296.2	— 178.8	— 88.2	— 7.8
650	— 730.2	. . .	. . .	— 244.3	— 145.9	— 56.3
700	. . .	. . .	. . .	. . .	— 222.4	— 132.0

Upper curve, up-stream from the crest.

The origin of abscissas is 34 mm. from the crest for experiments 1, 2, 3, 4 and 6, and 35 mm. for experiment 5.

Crest.	169.6	206.8	248.4	289.8	334.8	373.7
0	175.4	214.4	256.7	299.0	341.3	381.1
50	183.0	223.8	267.3	310.3	353.5	391.6
100	191.9	229.7	274.8	318.3	359.9	398.9
150	191.6	233.6	280.1	322.4	366.7	406.0
250	197.8	238.3	288.1	331.4	374.2	418.4
350	196.8	244.1	291.0	336.6	383.7	425.1
450	199.4	245.1	293.5	340.2	387.1	430.0
550	201.3	246.8	294.8	344.4	389.5	434.6
650	200.2	247.6	295.9	345.3	391.9	438.9
750	202.3	249.4	298.2	346.5	394.7	440.9
850	203.3	248.9	297.7	347.5	393.7	443.7
950	202.7	249.5	299.5	348.9	396.0	443.5
1,050	202.8	249.5	298.5	348.3	396.9	444.0
1,150	204.5	249.9	299.1	350.1	396.9	444.1
1,250	204.8	250.4	298.7	349.2	397.1	445.7

Profiles of Nappes.

Weir 1.13 m. (3.7 feet) high, inclined 3 : 2 down-stream. (See Series No. 15.)

Abscissas.	Ordinates.					
	Expt. No. 1. Head 200	Expt. No. 2. Head 250	Expt. No. 3. Head 301	Expt. No. 4. Head 353	Expt. No. 5. Head 399	Expt. No. 6. Head 444
	Lower curve.					
The origin of abscissas is 11 mm. from the crest for experiments 1, 2, and 3, and 10 mm. for experiments 4, 5 and 6.						
Crest.	0.0	0.0	0.0	0.0	0.0	0.0
0	7.7	8.8	8.6	9.0	9.3	8.2
10	10.1	11.7	12.6	15.2	13·5	12.7
20	11.6	13.7	16.1	17.9	17.7	17.1
30	11.9	14.8	16.8	18.9	18.9	21.4
40	12.1	15.3	18.8	19.7	21.5	23.8
50	11.8	15.4	18.8	20.8	23.8	24.6
60	9.2	14.1	18.6	20.9	24.2	26.5
70	6.9	12.3	16 9	21.1	24.4	27.0
80	4.5	10.7	17.0	20.9	24.6	27.2
90	— 0.1	8.5	14.8	20.6	25.5	27.2
100	— 2.2	6.2	13.9	18.9	25.2	27.0
110	— 6.6	2.3	9.8	17.6	23.2	26.7
120	. . .	0.2	8.0	16.4	20.5	27.0
130	— 17.9	— 6.3	6.0	13.7	18.5	25.2
140	. . .	. . .	2.1	11 6	15.4	25.2
150	— 28.8	— 12.9	— 0.5	7.7	15.0	22.2
160	. . .	. .	. .	2.5	11.9	19.2
170	— 42.1	— 22.8	— 9.0	1.7	8.9	18.1
180	. . .	. . .	. . .	. . .	6.9	14.7
190	— 57.8	— 36.0	— 17.9	— 5.2	5.7	10.2
200	. . .	. . .	. . .	. . .	0.7	8 5
210	— 71 4	— 47.9	— 32.3	— 15.8	— 3.7	6.5
220		. . .	. . .	. .	. . .	2.9
230	. . .	— 59.0	— 40.8	— 26.2	— 11.3	. . .
240	—102.1	. .	. .	.	. .	— 4.0
250	. . .	— 79.0	— 55.1	— 35.1	— 22.6	. . .
260	. .	. . .	. . .	. . .	. . .	— 13.5
270	—131.0	. . .	. .	. . .	. . .	. . .
280	. . .	—103.9	— 74.7	— 53.7	— 33.7	— 27.8
300	—161.8	. . .	. . .	. . .	. . .	. .
310	. .	—132.9	—100.2	— 72.3	— 55.1	— 38.9
330	—199.2	. . .	. .	. . .	. . .	. . .
340	.	—163.3	—130.0	— 96.1	— 71.5	— 52.3
370	—263.2	—199.7	—153.2	—117.9	. .	. . .
390	.	. . .	. . .	. . .	—114.8	— 90.9
410	—321.6	—253.5	—198.0	—157.5	. . .	. . .
440	. . .	. . .	. . .	. . .	—153.5	—126.0
450	—399.8	—318.2	—248.2	—195.9	.	. . .
490	—481.9	—368.6	—293.4	—244.3	—200.1	—161.6
540	. . .	—452.5	—356.7	—298.1	. . .	—214.5
590	. . .	. . .	. . .	. . .	—306.4	. . .
640	. . .	. . .	. . .	. . .	. . .	—320.6

Abscissas.	Ordinates.					
	Expt. No. 1. Head 200	Expt. No. 2. Head 250	Expt. No. 3. Head 301	Expt. No. 4. Head 353	Expt. No. 5. Head 399	Expt. No. 6. Head 444
Upper curve, down-stream from the crest.						
The origin of abscissas is 17 mm. from the crest for experiments 1, 2 and 3, and 16 mm. for experiments 4, 5 and 6.						
Crest.	162.0	203.7	243.4	288.6	323.6	363.5
0	156.5	198.0	240.1	283.2	321.2	359.4
50	140.5	183.9	224.8	270.1	304.3	343.0
100	116.5	160.6	205.0	249.1	290.3	324.8
150	87.3	134.2	183.5	231.3	269.8	308.3
200	48.0	102.4	154.8	204.4	246.4	288.5
250	— 2.8	61.9	120.1	162.7	216.6	262.5
300	— 57.6	14.8	80.1	138.9	188.8	230.7
350	— 133.8	— 37.5	32.0	103.1	151.3	195.8
400	— 204.3	— 102.5	— 18.3	49.7	107.4	161.7
450	— 296.8	— 170.3	— 79.9	2.5	62.7	122.6
500	— 396.0	— 247.4	— 142.3	— 52.2	16.4	75.7
550	. . .	— 338.6	— 213.3	— 112.1	— 40.9	28.4
600	. . .	. . .	— 298.9	— 181.1	— 95.3	— 29.2
650	. . .	. . .	. . .	. . .	— 231.4	— 146.2
Upper curve, up-stream from the crest.						
The origin of abscissas is 33 mm. from the crest for experiments 1, 2 and 3, and 34 mm. for experiments 4, 5 and 6.						
Crest.	162.0	203.7	243.4	288.6	323.6	363.5
0	168.7	209.8	250.7	296.5	333.4	369.7
50	177.6	217.8	260.4	306.4	344.1	381.4
100	183.6	225.9	270.4	312.7	350.9	389.0
150	187.0	231.7	274.5	319.9	359.3	398.0
250	190.9	238.7	284.0	332.2	371.2	410.7
350	195.7	241.5	288.8	336.3	378.9	416.4
450	196.9	244.7	294.2	338.9	382.1	424.5
550	199.2	246.1	296.3	343.2	386.9	429.2
650	197.7	248.2	296.6	346.7	391.1	431.2
750	199.6	249.0	299.4	348.8	394.1	434.4
850	200.3	250.4	299.8	349.6	394.4	437.7
950	200.0	251.9	299.1	350.6	395.2	438.1
1.050	199.1	250.4	300.6	351.1	398.1	440.0
1.150	200.8	248.9	301.3	351.2	397.9	439.8
1.250	200.6	251.0	300.7	351.1	398.8	440.1

Profiles of Nappes.

Weir 1.13 m. (3.7 feet) high, inclined 45° down-stream. (See Series No. 16.)

Abscissas.	Ordinates.					
	Expt. No. 1. Head 201	Expt. No. 2. Head 253	Expt. No. 3. Head 301	Expt. No. 4. Head 352	Expt. No. 5. Head 398	Expt. No. 6. Head 436
	Lower curve.					
The origin of abscissas is 10 mm. from the crest for experiment 1, 9 mm. for experiments 2, 3 and 6, and 8 mm. for experiments 4 and 5.						
Crest.	0.0	0.0	0.0	0.0	0.0	0.0
0	4.3	4.6	6.1	5.0	7.0	5.9
10	6.6	7.9	7.7	9.1	10.2	10.2
20	8.7	9.3	10.1	10.8	12.9	13.2
30	7.6	9.8	11.5	12.8	16.1	16.0
40	6.6	10.1	13.0	13.6	17.2	17.1
50	6.0	9.8	11.8	14.3	17.3	18.2
60	4.6	8.5	12.6	14.0	17.9	19.3
70	1.7	7.7	11.4	15.0	17.4	19.6
80	— 2.5	5.0	10.7	13.5	16.4	18.3
90	— 4.7	2.8	7.8	11.4	16.9	18.0
100	— 8.0	— 0.2	5.6	9 6	16.2	17.9
110	— 11.8	— 4.2	3.4	8.8	14.2	16.4
120	— 18.3	. . .	— 0.4	6.3	12.0	14.9
130	— 24.6	— 10.8	— 3.7	3.9	8.5	12.8
140	. . .	. .	. . .	1.0	7.0	10.7
150	— 33.7	— 21.6	— 10.1	— 1.3	5.4	9.5
160		. . .	. . .	. . .	3.2	6.9
170	— 47.5	— 29.8	— 19.5	— 9.4	— 2.0	5.0
180	. .	. . .	. .	. . .	. . .	0.4
190	— 63.5	— 40.3	— 28.8	— 16.6	— 8.2	— 2 2
200	. . .	. . .	.	. . .	. . .	.
210	— 79.2	— 54.7	— 38.8	— 32.5	— 15.9	. . .
220	. . .	. . .	. .	.	. . .	— 13.4
230	.	. . .	. . .	— 36.4	— 25.5	. .
240	— 107.6	— 76.0	— 59.3	. . .	. . .	— 20.8
250	. . .	. . .	. . .	— 47.7	— 33.6	.
260	. . .	. . .	. . .	. . .	. . .	— 27.8
270	— 138.9	— 101.0	— 77.9	— 59.0	— 43.8	. . .
280	. . .	. . .	. . .	. . .	. . .	— 44.3
290	— 157.8	. . .	. .	.	. .	.
300	. . .	— 127.0	— 99.3	— 78.1	— 61.6	— 48.9
320	— 201.4	. . .	. . .	. . .	. .	— 61.7
330	. . .	— 160.6	. . .	— 101.7	— 82.5	. .
340	. . .	. . .	— 137.2	. . .	. . .	— 73.5
350	— 242.0	. . .	. . .	. . .	. . .	. . .
360	. . .	— 193.4	. . .	— 124.6	— 98.7	— 84.9
380	. . .	. . .	— 177.8	. . .	. . .	. . .
390	— 302.0	— 232.9	. . .	. . .	. . .	— 110.1
400	. . .	. . .	. . .	— 158.0	— 133.9	.
420	. . .	— 268.3	. . .	. . .	. . .	— 130.1
430	. . .	. . .	— 229.3	. .	. . .	. . .
440	— 373.0	. . .	. . .	— 198.9	— 170.2	. . .

Abscissas.	Ordinates.					
	Expt. No. 1. Head 201	Expt. No. 2. Head 253	Expt. No. 3. Head 301	Expt. No. 4. Head 352	Expt. No. 5. Head 398	Expt. No. 6. Head 436
450	. . .	— 307.0	. . .	. . .	. . .	— 149.2
470	. . .	. . .	— 268.6	. . .	. . .	.
480	. . .	. .	. . .	. . .	. . .	— 181.0
490	— 475.0	— 369.0	. . .	— 249.2	— 217.4	
520	. . .	.	. . .	. . .	. . .	— 218.0
540	. . .	— 449.0	— 367.8	— 308.5	— 271.0	. . .
560	. . .	. . .	. . .	.	. . .	— 257.0
590	. . .	— 538.5	. . .	— 375.2	— 325.3	. . .
600	. . .	. . .	. .	. . .	. . .	— 303.0

Upper curve, down-stream from the crest.

The origin of abscissas is 16 mm. from the crest for experiments 1 and 2, and 15 mm. for experiments 3 and 6.

Crest.	157.7	199.5	239.5	281.1	315.4	349.2
0	153.2	194.4	233.5	275.9	310.8	344.2
50	135.7	179.4	218.3	259.7	296.9	328.4
100	111.6	157.1	196.6	241.6	280.2	312.0
150	82.4	131.1	174.9	221.3	260.1	292.5
200	41.2	94.8	143.9	194.2	233.8	268.4
250	— 12.0	57.2	112.4	163.0	207.7	240.6
300	— 68.0	15.5	70.4	126.5	174.0	209.2
350	— 130.2	— 42.7	25.3	87.3	137.7	179.0
400	— 201.1	— 105.8	— 24.9	42.4	98.1	142.0
450	— 299.5	— 170.8	— 95.1	— 6.1	55.6	101.1
500	— 390.8	— 249.8	— 149.5	— 61.0	1.7	54.8
550	— 498.3	. . .	— 223.1	. .	— 46.8	7.9
600	. .	— 427.3	. . .	— 188 0	— 108.6	— 52.8
650	. . .	. . .	. . .	. . .	— 166.0	— 105.8
700	. . .	— 629.3	. . .	— 345.0	— 238.8	. . .

Upper curve, up-stream from the crest.

The origin of abscissas is 34 mm. from the crest for experiments 1 and 2, and 35 mm. for experiments 3 and 6.

Crest.	157.7	199.5	239.5	281.1	315.4	349.2
0	165.3	208.1	246.5	288.0	325.3	357.2
50	177.0	217.6	256.4	299.0	335.1	365.5
100	182.9	224.7	264.8	305.9	347.2	374.9
150	185.7	231.7	271.9	313.7	353.0	385.2
200	. . .	235.4	. . .	319.8	360.0	. . .
250	193.7	238.7	278.9	325.1	365.4	395.2
350	195.5	241.3	283.1	332.8	373.3	406.0
450	196.9	243.7	286.2	338.2	377.9	412.3
550	198.0	245.2	290.5	341.6	382.8	419.0
650	199.9	250.4	293.4	344.0	387.2	422.8
750	203.0	248.1	294.3	345.4	388.6	424.9
850	202.7	249.4	296.6	346.6	389.6	425.5
950	199.9	253.0	296.6	348.2	392.6	429.4
1,050	202.5	251.8	297.3	349.0	393.4	429.8
1,150	202.6	252.1	298.2	349.9	394.4	432.2
1,250	203.0	253.2	301.4	351.0	396.8	431.9

Profiles of Nappes.

Weir 1.13 m. (3.7 feet) high, inclined 1 : 2 and 1 : 4 down-stream. (See Series Nos. 17 and 18.)

Abscissas.	Ordinates. Inclination 1 : 2. Expt. No. 1. Head 205	Expt. No. 2. Head 302	Expt. No. 3. Head 401	Inclination 1 : 4. Expt. No. 1. Head 208	Expt. No. 2. Head 304	Expt. No. 3. Head 404
	Lower curve. The origin 0 of abscissas is 5 mm. from the crest for both inclinations.					
Crest.	0.0	0.0	0.0	0.0	0.0	0.0
0	. . .	. . .	. . .	0.3	0.2	0.3
5	1.6	0.9	0.7	0.7	0.7	1.0
10	. . .	. . .	. . .	0.5	0.6	1.0
15	2.1	2.5	2.7	— 0.4	0.7	1.2
20	2.3	. . .	.	— 1.2	0.4	0.9
25	2.0	2.7	4.2	— 2.0	— 0.5	0.4
35	0.6	3.6	5.2	— 4.0	— 2.0	— 0.5
45	— 2.0	1.3	5.7	— 6.0	— 3.2	— 1.1
55	— 3.9	0.1	4.7	— 8.9	— 5.9	— 3.0
65	— 6.1	— 1.3	4.3	— 12.5	— 7.8	— 3.5
75	— 9.7	— 1.8	2.2	— 16.1	— 8.9	— 6.8
85	— 13.0	— 4.9	0.4	— 20.8	— 14.0	— 9.8
95	— 16 9	— 7.3	— 0.8	— 25.1	— 17.7	— 12.3
105	. . .	— 9 7	— 2.7	. . .	. . .	. . .
115	— 26.6	. . .	. .	— 35.7	— 25.8	— 17.5
125	. .	— 14.2	— 7.8	. . .	. . .	. . .
135	— 37.9	.	. . .	— 47.2	— 31.7	— 23.2
145	. . .	— 25.0	— 11.6	. . .	. . .	. . .
155	— 49.4	. . .	. .	— 59.7	— 43.8	— 32.8
165	. . .	— 35.6	— 21.3	. . .	. . .	. . .
175	— 63.1	. . .	. .	— 74.4	— 54.7	— 42.0
185	. .	— 43.0	— 28.1	. . .	. .	. . .
195	— 80.8	. . .	. .	— 90.8	— 65.1	— 51.3
205	. .	— 56.3	— 33.7	. . .	. . .	. .
215	— 95.4	. . .	. . .	— 107.4	— 77.5	. . .
225	. . .	— 66.5	— 45.8	. . .	. . .	— 65.3
235	— 115.9	. . .	. . .	. . .	. . .	. . .
245	. . .	— 80.9	— 56.3	— 138.7	— 100.5	. .
255	. . .	. .	. . .	. . .	. . .	— 83.2
265	— 146.9	— 97.9	— 65.7	. . .	. . .	. .
275	. . .	. . .	. . .	— 170.9	— 124.9	. . .
285	. . .	. . .	. . .	. .	. . .	— 102.6
295	— 181.6	— 116.7	— 85.2	. .	. . .	. . .
305	. . .	. . .	. . .	— 205.9	— 149.3	. .
315	. . .	. . .	. . .	. . .	. . .	— 122.8
325	— 217.6	— 143.1	— 106.3	. . .	. . .	. . .
335	. . .	. . .	. . .	— 245.7	— 178.3	. . .
345	. . .	. . .	. . .	. . .	. . .	— 143.3
355	. . .	— 170.7	— 127.3	. . .	. . .	. . .
365	— 273.5	. . .	. . .	. . .	. . .	. . .
375	. . .	. . .	. .	— 299.3	— 218.5	. . .
385	. . .	— 205.5	— 150.4	. . .	. . .	— 178.3
405	— 332.3	. . .	. . .	. . .	. . .	. . .
415	. . .	. . .	. . .	— 366.3	— 260.7	. . .
425	. . .	— 252.6	— 184.4	. . .	. . .	— 211.8

BAZIN-WEIRS.

Fig. 1 Pressures and Velocity in the interior of the nappe. Weir 1.13 metres (3.7 feet) high.

SCALES.

Abscissæ ($\frac{z}{h}$): om. 01 = 0.02.

Ordinates ($\frac{p}{h}$, $\frac{u^2}{2gh}$ and $\frac{u}{\sqrt{2gh}}$): om. 01 = 0.05.

Z = height of orifice above crest.
P = pressure head.
U = velocity.

Fig. 2 Apparatus for measuring the pressures and velocities

Fig. 3 Tubes indicating heads, pressures and velocities, respectively.

Heads

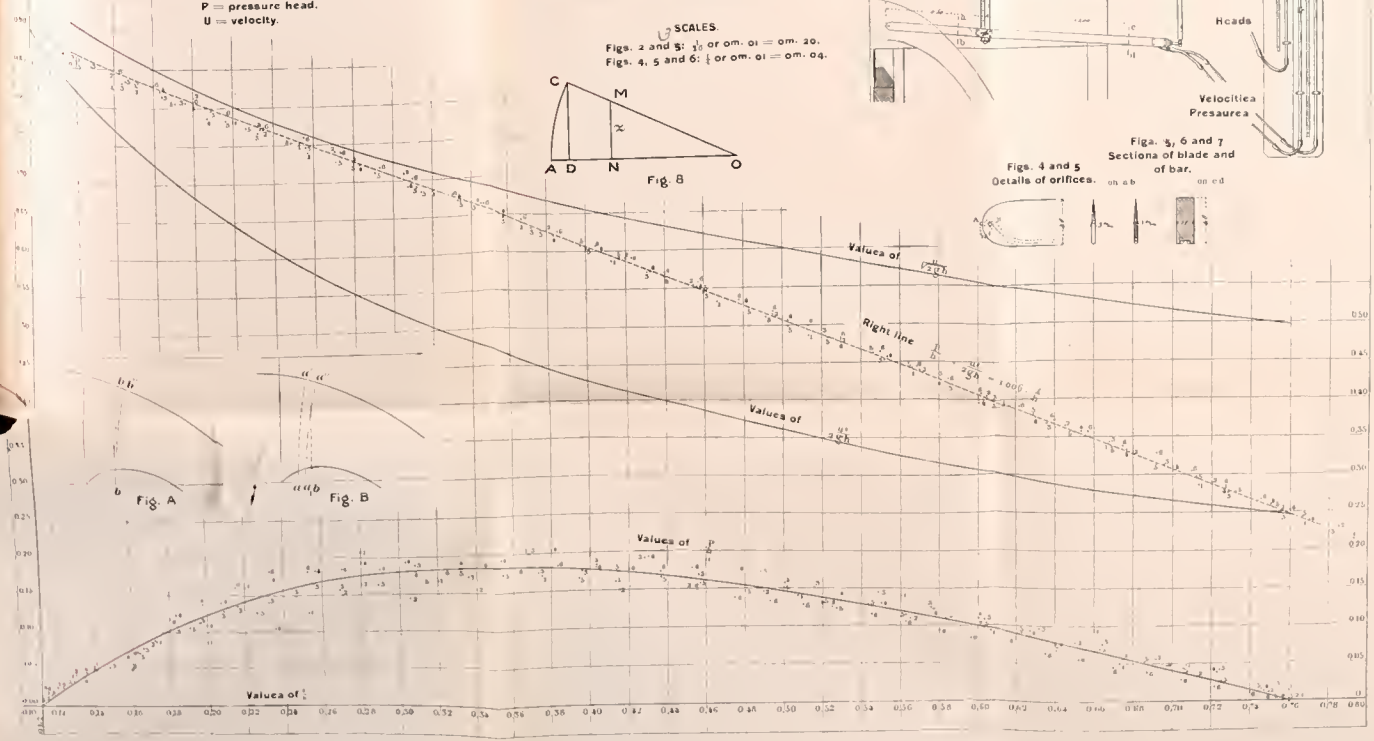
Velocities
Pressures

SCALES.
Figs. 2 and 3: $\frac{1}{10}$ or om. 01 = om. 20.
Figs. 4, 5 and 6: $\frac{1}{5}$ or om. 01 = om. 04.

Fig. 8

Figs. 4 and 5
Details of orifices.

Figs. 5, 6 and 7
Sections of blade and of bar.



Abscissas.	Ordinates.					
	Inclination 1 : 2.			Inclination 1 : 4.		
	Expt No. 1. Head 205	Expt. No. 2. Head 302	Expt. No. 3. Head 401	Expt. No. 1. Head 208	Expt. No. 2. Head 304	Expt. No. 3. Head 404
445	— 396.6	. . .	. . .	. . .	— 296.9	. . .
455	. . .	. . .	. . .	— 431.5	. . .	. . .
465	. . .	— 293.4	— 224.8	. . .	. . .	— 252.6
475	. . .	. . .	. . .	. . .	— 338.8	. . .
485	— 474.4	. . .	. . .	. . .	. . .	. . .
495	. . .	. . .	. . .	— 512.2	. . .	. . .
505	. . .	— 337.9	— 262.3	. . .	. . .	— 293.1
515	. . .	. . .	. . .	. . .	— 390.0	. . .
535	— 569.0	. . .	. . .	. . .	. . .	. . .
545	. . .	— 401.4	— 308.1	. . .	. . .	— 337.2
555	. . .	. . .	. . .	. . .	— 451.5	. . .
585	— 678.0	— 471.3	— 360.7	. . .	. . .	. . .
595	. . .	. . .	. .	. . .	. . .	— 391.0
645	— 824.3	— 554.3	— 421.4	. . .	. . .	. . .
695	. . .	— 642.4	— 490.1	. . .	. . .	. . .

Upper curve, down-stream from the crest.

The origin 0 of abscissas is 18 mm. from the crest for the inclination of 1 : 2, and 17 mm. for the inclination of 1 : 4.

Crest.	148.4	221.2	295.8	136.7	199.9	269.6
0	143.9	215.9	290.9	131.7	196.1	263.4
50	124.7	199.3	273.4	112.7	179.8	248.5
100	99.9	179.3	255.2	85.8	156.9	228.4
150	67.4	153.0	233.6	52.6	129.8	206.1
200	25.8	123.1	205.1	12.9	98.5	178.2
250	— 21.0	87.9	178.3	— 41.4	63.1	148.5
300	— 82.6	45.7	149.7	— 99.1	17.0	113.4
350	— 147.5	— 1.0	104.3	— 161.4	— 32.8	73.1
400	— 221.4	— 55.4	64.8	— 244.1	— 84.9	34.5
450	— 316.8	— 113.9	21.9	— 328.1	— 144.0	. . .
500	— 401.9	— 181.9	— 31.0	— 419.8	— 211.1	— 68.5
550	. . .	. . .	. . .	— 531.6	. .	. . .
600	— 616.0	— 318.9	— 142.0	. . .	— 358.6	— 181.8
700	. . .	— 491.6	— 311.0	. . .	. . .	— 317.4

Upper curve, up-stream from the crest.

The origin 0 of abscissas is 32 mm. from the crest for the inclination of 1 : 2, and 33 mm. for the inclination of 1 : 4.

Crest.	148.4	221.2	295.8	136.7	199.9	269.6
0	155.8	229.6	305.4	143.9	210.0	279.2
50	164.0	239.9	315.3	158.3	219.7	288.2
100	173.0	250.6	326.0	164.0	233.1	300.5
150	178.8	257.3	334.5	170.4	239.2	310.1
200	183.9	262.6	340.7	174.7	245.6	316.6
250	188.6	269.0	347.8	180.5	251.0	324.6
350	190.2	275.0	360.0	186.5	261.1	335.6
450	195.0	281.0	367.9	188.7	266.7	346.9
550	198.0	285.4	371.7	190.9	272.4	353.6
650	198.3	288.9	376.8	192.9	277.0	358.7
750	200.2	290.9	379.7	196.1	279.9	364.1
850	204 6	293.4	383.1	199.7	284.1	368.0
950	201.2	294.0	386.2	197.2	280.4	371.4
1,050	202.7	295.7	388.2	202.1	284.7	375.8
1,150	202.7	296.5	389.9	202.0	288.7	377.8
1,250	204.3	297.7	392.2	203.5	290.3	380.8

Profiles of Nappes.

Weir 0.35 m. (1.15 feet) high, inclined 45° up-stream and down-stream. (See Series Nos. 23 and 28.)

Abscissas.	Ordinates.					
	Inclination 45° up-stream.			Inclination 45° down-stream.		
	Expt. No. 1. Head 205	Expt. No. 2. Head 296	Expt. No. 3. Head 387	Expt. No. 1. Head 201	Expt. No. 2. Head 302	Expt. No. 3. Head 391
	Lower Curve.					
For both inclinations, the origin 0 of abscissas is 5 mm. from the crest in experiment 1, and 4 mm. in experiments 2 and 3.						
Crest.	6.7	10.1	14.0	0.0	0.0	0.0
0	13.5	14.5	20.7	3.3	4.0	4.7
5	16.1	18.9	18.4	4.7	6.7	8.7
10	. . .	. . .	. . .	6.1	7.6	. . .
15	21.9	24.5	26.6	7.5	8.9	12.1
20	. . .	. . .	. . .	8.3	9.8	. . .
25	24.4	31.5	32.1	8.8	11.5	12.0
30	. . .	. . .	. . .	8.7	11.8	. . .
35	25.7	33.9	35.4	8.5	12.1	13.9
45	27.1	34.5	38.0	6.9	12.0	15.6
55	25.4	34.8	40.7	6.3	12.5	15.6
65	24.7	35.1	43.7	4.5	13.0	15.7
75	23.4	36.6	45.2	1.5	11.7	16.1
85	21.0	36.5	46.2	— 1.5	9.4	15.7
95	16.7	35.8	46.2	— 4.9	7.6	15.4
105	12.8	35.3	44.4	— 8.7	5.5	13.5
115	11.9	31.6	42.1	. . .	4.1	12.8
125	7.6	29.8	39.1	— 16.4	0.0	11.0
135	2.7	24.6	. . .	. . .	. . .	9.1
145	— 7.7	. . .	36.1	— 26.5	— 6.3	5.5
155	— 9.2	16.8	. . .	. . .	. .	3.6
165	— 17.0	. . .	28.0	— 37.8	— 11.6	— 1.3
175	. . .	9.6	. . .	. . .	. . .	— 1.6
185	— 31.3	. . .	25.0	— 52.6	— 20.5	. . .
195	. .	3.9	. . .	. . .		— 9.0
205	— 42.1	. . .	19.3	. . .	— 31.2	.
215	. . .	— 12.4	. . .	— 77.0	.	— 18.0
225	— 65.2	. . .	11.7	. . .	— 43.2	. .
235	. . .	. . .	. . .	. . .	. . .	— 27.3
245	— 88.1	— 25.4	5.6	— 101.0	. . .	. . .
255	. . .	. . .	. . .	. . .	— 58.2	— 39.0
265	— 103.1	. . .	— 3.8	. . .	. . .	.
275	. . .	— 45.7	. . .	— 132.6	. .	— 43.6
285	. . .	. . .	— 13.0	. . .	— 79.2	. .
295	. .	. . .	. . .	. . .	. . .	— 61.9
305	. . .	— 68.6	. . .	— 166.4	. . .	. . .
315	. . .	. . .	— 33.3	. . .	— 101.6	. . .
325	. . .	. . .	. . .	. . .	. . .	— 70.0
335	. . .	. .	. . .	— 204.8	. .	. . .
345	. . .	— 99.9	— 45.2	. . .	— 120.7	. . .
355	. . .	. . .	. . .	. . .	. . .	— 92.9
375	. . .	.	— 67.1	— 255.8	.	. .
385	. . .	— 140.6	. . .	. . .	— 160.1	— 110.6
405	. . .	. . .	— 96.0	. . .	. . .	. . .
415	. .	.	. . .	— 338.5	. . .	. . .
425	. . .	— 184.2	. . .	. . .	— 203.5	— 146.8

Abscissas.	Ordinates.					
	Inclination 45° up-stream.			Inclination 45° down-stream.		
	Expt. No. 1. Head 205	Expt. No. 2. Head 296	Expt. No. 3. Head 387	Expt. No. 1. Head 201	Expt. No. 2. Head 302	Expt. No. 3. Head 391
445	. . .	. . .	— 126.1	. . .	. . .	. . .
455	. . .	. . .	. . .	— 394.5	. . .	. . .
465	. . .	— 233.0	. . .	. . .	. . .	— 180.7
475	. . .	. . .	. . .	. . .	— 260.3	. . .
485	. . .	. . .	— 167.6	. . .	. . .	. .
495	. . .	. . .	. . .	— 454.2	. . .	. . .
505	. .	. . .	. . .	. . .	. . .	— 210.1
515	. . .	— 312.4	. . .	. .	. . .	. . .
525	. . .	. . .	— 207.8	. . .	— 327.3	
545	. . .	. .	. . .	. . .	. . .	— 266.3
565	. . .	— 380.5	— 248.9	.	. . .	. . .

Upper curve, down-stream from the crest.

For both inclinations, the origin 0 of abscissas is 16 mm. from the crest in experiment 1, and 15 mm. in experiments 2 and 3.

Crest.	177.9	256.5	332.9	161.1	245.3	331.5
0	177.4	249.8	333.5	155.8	245.9	325.1
50	157.7	239.8	320.0	142.3	229.0	309.5
100	134.1	219.7	304 0	117.1	206.3	291.7
150	103.1	198.6	286.0	85.4	196.8	258.1
200	64.1	165.7	263.1	50.7	160.6	247.2
250	10.0	131.3	240.6	2.5	124.9	220.7
300	— 47.5	94.8	205.9	— 53.7	88.0	181.5
350	— 118.6	47.3	168.8	— 121.9	40.9	151.6
400	. . .	— 9.2	126.6	— 192.1	— 9.9	106.4
450	. . .	— 70.2	85.0	— 278.4	— 65.8	68.1
500	. . .	— 136.7	26.6	— 369.4	— 124.5	31.8
550	. . .	— 208.1	— 30.0	— 480.6	— 193.7	— 26.4
600	. . .	— 291.8	— 79.8	. . .	. . .	— 93.2
650	. . .	. . .	. . .	. .	. . .	— 146.6

Upper curve, up-stream from the crest.

For both inclinations, the origin 0 of abscissas is 34 mm. from the crest in experiment 1, and 35 mm. in experiments 2 and 3.

Crest.	177.9	256.5	332.9	161.1	245.3	331 5
0	182.1	263.7	345.7	167.6	253.1	333 5
50	189.5	272.4	353.7	177.0	265.2	341.2
100	196 2	277.8	357.8	183.3	272.3	350.2
150	200.5	281.6	362.6	190.3	278.4	360.3
200	200.3	. . .	370.4	190.7	284.0	365.3
250	201.2	289.0	373.4	194.4	289.6	370.5
300	. . .	. . .	376.4	. . .	. .	. . .
350	202.2	289.7	376.3	198.1	291.4	374.2
400	. . .	.	380.9	. . .	. . .	. . .
450	202.3	293.8	377.7	196.8	293.4	380.5
500	. . .	. .	380.4	. . .		. . .
550	204.3	296.0	384.6	198.5	299.6	385.8
650	207.1	293.5	386.1	200.9	299.0	387.8
750	205.1	297.2	385.9	202.1	301.6	386.2
850	204.2	298.7	383.0	202.8	301.1	385.3
950	204.6	.	386.2	203.1	301.5	391.3
1,050	204.1	294.1	385.9	201.3	301.7	389.4
1,150	203.9	. . .	386.9	200.5	302.7	391 6
1,250	203.1	295.0	383.3	200.6	301.7	390.4

Profiles of Nappes.

Weir 0.35 m. (1.15 feet) high, inclined 1 : 2 and 1 : 4 down-stream. (See Series Nos. 29 and 30.)

Abscissas.	Ordinates. Inclination 1 : 2. Expt. No. 1. Head 203	Expt. No. 2. Head 299	Expt. No. 3. Head 390	Inclination 1 : 4. Expt. No. 1. Head 202	Expt. No. 2. Head 299	Expt. No. 3. Head 404
	Lower curve. For both inclinations the origin 0 of abscissas is 4 mm. from the crest.					
Crest.	0.0	0.0	0.0	0.0	0.0	0.0
0	2.3	2.4	4.0	0.4	0.3	0.9
5	2.7	3.7	4.1	0.9	0.8	1.1
10	3.7	4.8	4.2	0.3	0.8	1.5
15	4.1	4.9	5.3	— 0.9	0.1	1.5
20	3.6	5.4	5.8	. . .	. . .	0.8
25	3.2	5.4	6.8	— 2.3	— 0.9	0.7
30	3.1	5.6	7.1	. . .	. . .	0.0
35	2 7	5.2	6.7	— 4.7	— 2.7	— 0.6
40	0.8	. . .	6.5	. . .	. . .	. .
45	0.2	3.9	6.4	— 7.1	— 4.6	— 2.5
55	— 2.8	2.4	6.6	— 10.3	— 6.4	— 4.1
65	— 6.3	— 0.1	6.9	— 13.9	— 9.7	— 5.5
75	— 8.7	— 1.6	4.8	— 17.9	— 12.1	— 7.3
85	— 13.5	— 3.5	4.3	— 21.6	. . .	— 8.4
95	— 16.2	— 6.7	0.8	— 26.0	— 19.0	— 11.3
105	— 22.4	— 8.3	— 2.1	. . .	. . .	— 13.6
115	— 27.5	— 12.0	— 4.1	— 37.1	— 26.1	— 18.0
125	— 33.3	.	— 7.9	. .	. .	— 21.0
135		— 17.8	.	— 49.8	— 34.2	— 23.5
145	— 41.6	. . .	— 12.3	. . .	. . .	. . .
155	. .	— 27.5	. . .	— 62.8	— 43.4	— 31.0
165	— 56.8	.	— 19.2	. .	. . .	. . .
175		— 38.3	. . .	— 77.7	— 53.7	— 36.3
185	— 71.8	.	— 27.0	. . .	. . .	. . .
195	. . .	— 49.3	. . .	— 93.3	. . .	— 49.4
205	— 83.1	. . .	— 36.1	. . .	— 72.5	. . .
215	. .	— 58.8	. . .	. . .	. . .	— 57.9
225	— 105.2	. . .	— 43.2	— 117.2	. . .	. .
235	. . .	. . .	. . .	. . .	— 90.7	— 68.1
245	. . .	— 77.9	. . .	. . .	. . .	. . .
255	. . .	. .	— 61.2	— 148.4	. .	. . .
265	— 145.8	. . .	. . .	. . .	— 112.3	— 84.5
275	.	— 98.0	. . .	. . .	. . .	. . .
285	. . .	. . .	— 78.8	— 184.1	. . .	. . .
295	— 174.8	. . .	. . .	. . .	— 138.4	— 105.7
305	. . .	— 124.6	. . .	. . .	. . .	. . .
315	. . .	. . .	— 96.0	. . .	. . .	. . .
325	. . .	. . .	. . .	— 233.9	. . .	— 121.9
335	— 224.4	— 146.8	. . .	. . .	— 172.5	. .
355	. . .	. . .	— 125.1	. .	. . .	— 143.7
365	. . .	. . .	. . .	— 292.5	. . .	. . .
375	— 285.0	— 184.5	. . .	. . .	— 214.8	. . .

Abscissas.	Ordinates. Inclination 1 : 2. Expt. No. 1. Head 203	Expt. No. 2. Head 299	Expt. No. 3. Head 390	Inclination 1 : 4. Expt. No. 1. Head 202	Expt. No. 2. Head 299	Expt. No. 3. Head 404
395	. . .	. . .	— 148.6	. . .	. . .	— 175.0
405	. . .	. . .	. . .	— 343.9	. . .	. . .
415	— 338.6	. . .	. . .	. . .	— 252.4	. . .
425	. . .	— 234.2	. . .	. . .	. . .	.
435	. .	. . .	. . .	. . .	. . .	— 209.2
445	. . .	. . .	— 196.8	— 416.4	.	. . .
455	. . .	. . .	. . .	. . .	— 296.1	. . .
465	— 416.1	. . .	. . .	. . .	. . .	. . .
475	. . .	— 294.2	. . .	. . .	. . .	— 246.3
495	. . .	. . .	— 245.0	— 505.9	— 353.7	. . .
515	— 511.8	. . .	. . .	. . .	. . .	— 286.3
525	. . .	— 349.6	. . .	. . .	. . .	. . .

Upper curve, down-stream from the crest.

For both inclinations the origin 0 of abscissas is 15 mm. from the crest.

Crest.	151.3	226.8	300.4	134.9	204.2	283.8
0	144.8	220.7	300.6	129.4	199.7	277.3
50	125.8	206.3	282.2	106.9	183.9	258.3
100	104.3	184.1	269.8	82.0	160 5	239.1
150	68.9	159.3	245.6	50.7	133.6	215.3
200	31.1	134.1	218.1	7.8	102.8	188.2
250	— 19.9	94.5	188.7	— 42.7	67.3	163.6
300	— 74.5	55.9	151.9	— 100.7	22.5	125.7
350	— 140.2	9.9	118.5	— 173.9	— 21.3	94.6
400	— 215.2	— 39.4	82.9	— 252.8	— 75.8	49.5
450	— 293.4	— 98.1	37.1	— 332.7	— 136.4	11.3
500	— 384.2	— 162.6	— 11.5	— 433.0	— 199.0	— 48.9
550	. . .	— 229.0	— 69.9	. . .	— 269.0	— 90.7
600	. . .	— 304.7	— 119.0	. . .	— 346.5	— 145.7
700	. .	. .	. . .	. . .	. . .	— 274.4

Upper curve, up-stream from the crest.

For both inclinations the origin 0 of abscissas is 35 mm. from the crest.

Crest.	151.3	226.8	300.4	134.9	204.2	283.8
0	160.7	237.6	310.9	142.2	211.8	292.4
50	168.4	242.9	322.8	152.7	223.3	302.3
100	176.4	252 3	333.8	161.1	233.3	313.3
150	180.0	261.7	340.9	166.8	243.6	322.4
200	185.8	267.4	348.3	173.3	248.6	330.6
250	191.6	277.8	353.2	174.0	252.0	338.4
350	195.1	281.6	361.1	183.1	263.5	350.7
450	196.2	285.5	368.1	186.6	269.9	361.9
550	199.8	290.1	373.5	189.5	283.5	367.6
650	201.3	294.5	378.1	191.0	278.8	373.6
750	201.6	296.5	379.4	193.4	280.5	385.8
850	202.9	294.8	383.9	193 6	285.3	387.7
950	203.5	295.6	389.7	195.2	290.5	388.5
1,050	204.0	296.1	389.3	196.9	290.1	396.3
1,150	202.5	296.8	387.1	200.3	293.5	395.3
1,250	204.9	295.6	386.3	200.2	292.5	400.4

Profiles of Nappes.

Vertical weir 1.13 m. (3.7 feet) high, with horizontal plate 0.15 m. (5.9 inches) wide projecting up-stream. (See Series No. 31.)

Abscissas.	Ordinates.				
	Expt. No. 1. Head 250	Expt. No. 2. Head 297	Expt. No. 3. Head 349	Expt. No. 4. Head 399	Expt. No. 5. Head 446
	Lower curve.				
The origin of abscissas is 14 mm. from the crest for experiments 1 and 3, and 13 mm. for experiments 2, 4 and 5.					
Crest.	17.5	20.0	22.2	26.3	25.9
0	32.4	36.7	42.5	43.0	50.3
10	40.5	43.7	49.6	52.5	57.9
20	44.4	47.9	53.2	58.2	61.2
30	45.1	52.0	55.3	62.6	65.9
40	46.2	51.0	57.3	66.8	69.8
50	47.7	52.2	61.3	66.4	74.7
60	46.8	53.3	59.7	74.5	71.7
70	44.4	52.3	58.9	76.3	75.8
80	43.8	53.1	61.0	70.0	75.0
90	42.5	51.9	62.7	66.6	77.1
100	37.8	48.8	61.6	67.8	81.0
110	33.0	45.4	58.1	65.1	81.6
120	29.4	. . . .	56.6	66.6	78.8
130	23.7	42.6	50.4	62.5	71.2
140	20.3	. . . .	48.3	62.6	71.3
150	20.6	29.5	48.2	66.2	73.3
160	16.9	. . . .	44.6	57.8	68.5
170	7.5	23.4	42.7	58.9	67.4
180	1.5	. . . .	36.6	55.9	63.1
190	— 4.5	19.1	34.0	55.4	62.1
200	. . . .	. . . .	28.0	51.9	60.0
210	— 22.8	5.1	26.8	42.0	58.7
220	. . . .	. . . .	19.2	37.9	49.2
230	— 35.8	. . . .	12.5	33.7	49.6
240	. . . .	— 19.0	11.3	35.5	43.7
250	— 50.0	. . . .	7.2	29.0	37.0
260	. . . .	. . . .	— 4.9	18.5	33.7
270	— 71.8	— 44.5	— 11.8	9.0	30.1
280	. . . .	. . . .	. . . .	8.6	24.8
290	— 95.4	. . . .	— 19.3	1.2	23.7
300	. . . .	— 63.9	. . . .	— 6.7	16.7
310	. . . .	. . . .	— 35.6	— 9.1	10.0
320	— 123.4	. . . .	. . . .	. . . .	1.2
330	. . . .	. . . .	— 49.2	— 26.1	— 1.0
340	. . . .	— 104.0	. . . .	. . . .	— 8.8
350	— 161.1	. . . .	— 70.2	— 40.7	. . . .
360	. . . .	. . . .	. . . .	. . . .	— 24.8
370	. . .	. . . .	— 83.4	— 53.5	. . . .
380	— 199.0	. . . .	. . . .	. . . .	— 44.3
390	. . . .	— 154.4	— 109.2	— 74.4	. .
400	. . . .	. . . .	. . . .	. . . .	— 52.8
410	— 246.3	. . . .	— 126.3	— 83.0	. . . .
420	. . . .	. . . .	. . . .	. . . .	— 69.2
440	— 292.8	. . . .	— 147.1	— 121.0	— 83.1
460	. . . .	. . . .	. . . .	. . .	— 103.6
470	— 338.3	. . . .	— 187.1	— 149.0	. . . .
490	. . . .	— 288.0	. . . .	. . . .	— 133.1
500	— 401.8	. . . .	— 228.8	— 169.0	. . . .

Abscissas.	Ordinates.				
	Expt. No. 1. Head 250	Expt. No. 2. Head 297	Expt. No. 3. Head 349	Expt. No. 4. Head 399	Expt. No. 5. Head 446
520	. . . .	. . . .	. . .	. . . .	— 161.5
530	. . .	. . . .	— 279.8	. . . .	. . . .
540	— 471.8	. . . .	. . . .	— 229.0	. .
550	. . . .	. . . .	. .	. . . .	— 187.5
560	. . . .	. . . .	— 315.0	. . . .	
580	. . . .	. . . .	. . . .	— 279.0	— 217.5
590	— 563.8	— 459.0	— 355.0	. . . .	. . .
610	. . . .	. . . .	. . . .	. . .	— 251.0
620	. . . .	. . . .	. . . .	— 328.0	. . . .
640	— 687.8	. . . .	— 441.0	.	— 298.0
660	. . . .	. . . .	. . . .	— 386.0	. . .
690	— 824.8	— 652.0	— 532.0	— 425.0	— 361.0

Upper curve, down-stream from the crest.

The origin of abscissas is 18 mm. from the crest for experiments 1 and 3, and 17 mm. for experiments 2, 4 and 5.

Crest.	217.8	259.2	304.4	346.9	388.0
0	212.0	254.4	299.9	342.5	382.6
50	196.2	239.2	286.4	331.4	369.9
100	175.9	220.2	268.2	313.0	353.7
150	151.3	196.3	243.7	296.0	336.3
200	114.0	167.0	218.9	269.0	312.7
250	71.1	129.7	189.8	240.0	286.1
300	16.4	87.0	151.3	206.5	258.3
350	— 42.5	36.0	106.2	168.4	221.5
400	— 112.3	— 20.0	63.6	125.8	181.0
450	— 190.3	. . . .	6.7	77.5	143.0
500	— 273.3	— 160.0	— 54.8	20.0	94.4
550	— 377.8	. . .	— 122.8	. . . .	. . . .
600	— 478.8	— 322.0	— 198.0	— 100.0	— 22.0
650	— 584.8	. . . .	— 284.0	. . .	. . . .
700	— 719.8	— 507.0	— 372.0	— 245.0	— 153.0

Upper curve, up-stream from the crest.

The origin of abscissas is 32 mm. from the crest for experiments 1 and 3, and 33 mm. for experiments 2, 4 and 5.

Crest.	217.8	259.2	304.4	346.9	388.0
0	223.0	265.0	308.3	354.7	394.4
50	231.8	272.0	317.1	362.2	402.5
100	238.2	. . . .	324.9	368.2	411.0
150	240.1	282.2	330.6	374.5	417.3
200	241.9	. . . .	335.2	. . . .	423.3
250	242.9	288.0	337.9	384.7	426.7
300	. . . .	. . . .	. . . .	. . . .	429.9
350	245.4	292.2	342.9	389.0	432.2
400	. . . .	. . .	. . .	. . . .	434.9
450	248.5	294.4	346.4	393.3	440.0
550	250.3	295.0	347.6	394.7	440.0
650	249.9	297.5	348.0	397.0	442.4
750	250.0	296.8	347.9	396.5	441.6
850	249.9	297.7	348.8	397.5	443.7
950	249.4	298.0	350.7	398.8	445.8
1.050	249.9	298.5	351.5	398.6	444.8
1.150	250.9	298.4	348.8	398.5	445.8
1.250	250.9	298.6	349.7	398.9	446.8

Profiles of Nappes.

Vertical weir 1.13 m. (3.7 feet) high, with horizontal plate 0.25 m. (9.8 inches) wide projecting up-stream. (See Series No. 32.)

Lower curve.

The origin 0 of abscissas is 8 mm. from the crest in both experiments.

Abscissas.	Ordinates. Expt. No. 1. Head 396	Ordinates. Expt. No. 2. Head 436
Crest.	32.5	31.6
0	45.0	45.3
10	47.8	51.0
20	51.1	55.9
30	57.0	58.5
40	63.4	63.8
50	62.6	65.0
60	63.8	65.9
70	65.8	69.8
80	66.8	70.8
90	68.1	73.5
100	67.4	74.4
110	66 0	74.0
120	66.6	73.7
130	64.1	73.3
140	62.8	70.9
150	58.5	69.0
160	56.7	68.9
170	55.5	65.5
180	53.1	63.1
190	49.1	58.6
210	40.0	50.9
230	31.5	45.1
250	24.8	36.8
270	10.1	29.1
290	3.6	18.1
320	— 11.9	1.5
350	— 39.2	— 12.9
390	— 69.8	— 43.1
430	— 106.4	— 78.4
470	— 158.1	— 116 5
520	— 195.9	— 162.0
570	— 257.4	— 215.6
620	— 332.9	— 299.8
670	— 391.4	— 335 9
720	— 470.9	— 392.1
770	— 542.4	— 473.9
820	— 651.1	— 576.9

Upper curve, down-stream from the crest.

The origin 0 of abscissas is 15 mm. from the crest in both experiments.

Abscissas.	Ordinates. Expt. No. 1. Head 396	Ordinates. Expt. No. 2. Head 436
Crest.	344.1	382.1
0	341.6	377.5
50	328.1	363.2
100	312.4	345.9
150	291.6	328.2
200	267.0	305.8
250	240.5	280.9
300	204.1	249.1
350	167.9	212.8
400	123.1	172.8
450	75.9	128.3
500	18.8	82.6
550	— 39.9	28.9
600	— 99.9	— 33.9
650	— 171.3	— 92.3
700	— 246.9	— 157.1
800	— 403.9	— 309.9

Upper curve, up-stream from the crest.

The origin 0 of abscissas is 35 mm. from the crest in both experiments.

Abscissas.	Ordinates. Expt. No. 1. Head 396	Ordinates. Expt. No. 2. Head 436
Crest.	344.1	382.1
0	352.7	390.3
50	364.1	398.0
100	368.9	402.1
150	374.6	409.1
200	378.3	415.8
250	381 7	419.7
350	388.2	423.1
450	390.8	428.1
550	391.9	430.6
650	394.8	432.1
750	395.7	433.6
850	396.3	435.5
950	397.3	435.9

Profiles of Nappes.

Weir 1.13 m. (3.7 feet) inclined 3 : 2 up-stream, and provided with a curved plate projecting up-stream. (See Series No. 33.)

Abscissas.	Ordinates.				
	Expt. No. 1. Head 322	Expt. No. 2. Head 353	Expt. No. 3. Head 373	Expt. No. 4. Head 400	Expt. No. 5. Head 448
	Lower curve.				
	The origin 0 of abscissas is 9 mm. from the crest in the five experiments.				
Crest.	25.5	24.0	28.0	28.9	28.4
0	35.8	39.4	39.3	37.5	38.0
10	39.5	43.5	42.4	46.5	46.8
20	48.5	49.5	53.6	53.6	54.8
30	50.0	55.8	54.8	57.9	60.6
40	52.6	56.0	59.8	60.6	59.8
50	56.6	57.5	62.0	60.8	71.8
60	56.6	61.8	62.8	66.5	73.0
70	55.8	58.0	62.3	68.8	74.7
80	55.8	60.6	63.1	67.5	77.4
90	56.0	60.2	61.6	68.5	73.8
100	55.1	54.7	61.7	73.6	72.7
110	54.0	58.2	61.8	67.2	69.2
120	50.9	55.0	61.4	64.3	73.5
130	45.8	53.3	58.4	65.0	73.3
140	46.4	51.3	59.0	65.5	68.5
150	41.8	51.4	53.5	60.1	66.6
160	38.8	46.6	49.6	58.1	65.7
170	35.0	43.3	47.9	49.3	65.6
180	31.0	37.0	47.3	48.1	61.0
190	29.7	32.1	44.0	46.7	58.0
200	27.2	30.6	41.5	42.8	58.4
210	14.2	30.5	38.2	40.8	53.2
220	7.6	28.9	31.8	37.8	52.3
230	6.0	17.1	29.7	29.8	49.0
240	— 2.5	11.8	21.9	29.2	44.7
250	. . . .	2.7	11.7	27.1	38.4
260	— 11.8	— 4.1	8.8	21.6	28.3
270	. . .	— 11.6	3.4	17.0	26.5
280	— 29.6	. . .	0.9	15.2	19.1
290	. . . .	— 18.1	— 11.5	0.1	16.7
300	— 44.6	. . .	. . . .	— 6.5	12.8
310	. . . .	— 25.5	— 23.7	— 11.1	9.2
320	— 60.1	. . . .	. . . .	. . . .	6.6
330	. . . .	— 52.6	— 41.7	— 23.4	4.9
340	— 75.0	. .	. . . .	. . . .	— 9.2
350	. .	— 71.3	— 57.0	— 42.1	. . . .
360	— 95.0	. .	. . . .	. . . .	— 20.2
370	. . . .	— 86.5	— 72.7	— 58.6	. . . .
380	. . .	. . . .	. .	. . . .	— 43.0
390	— 143.7	— 108.2	— 85.0	— 75.0	. . . .
400	. . . .	. . . .	. . . .	. . . .	— 45.6
410	. . . .	. . . .	— 107.2	— 90.2	. . . .

Abscissas.	Ordinates.				
	Expt. No. 1. Head 322	Expt. No. 2. Head 353	Expt. No. 3. Head 373	Expt. No. 4. Head 400	Expt. No. 5. Head 448
420	— 166.7	— 141.5	. . . .	. . . .	— 64.7
440	. .	. . .	— 133.4	— 122.2	— 83.5
450	— 202.7	— 169.5	. . . .	. . . .	. . . .
470	. . .	. . . .	— 168.2	— 150.2	— 102.7
490	— 256.7	— 214.5	. .	. . . .	. . . .
500	. . . .	. . . .	— 196.2	— 196.2	— 145.2
530	. . . .	. . . .	. . . .	. .	— 176.2
540	— 321.6	— 282.0	— 236.7	— 227.2	. . .
560	. . . .	. . . .	. . . .	. . .	— 190.2
590	— 407.2	— 354.5	— 324.2	— 290 2	— 234.2

Upper curve, down-stream from the crest.

The origin 0 of abscissas is 16 mm. from the crest in the five experiments.

Crest.	280.6	308.3	323.0	345.7	388.7
0	277.1	303.7	317.9	341.0	383.8
50	263.8	290.5	295.1	328.3	367.9
100	245.2	272.2	290.2	310.5	354.3
150	224.3	249.5	267.8	287.8	335.0
200	192.8	219.5	243.7	267.4	311.3
250	161.4	191.5	213.2	240.6	286.1
300	120.5	154.9	178.1	211.3	256.0
350	69.6	110.7	135.8	168.8	219.8
400	18.4	63.5	93.3	128.0	184.0
450	— 44.7	8.8	38.0	75.2	141.7
500	— 113.5	— 50.5	— 19.3	30.4	95.5
550	— 177.2	— 125.5	— 83.0	— 35.5	43.6
600	— 274.2	— 194.5	— 156.6	— 87.2	— 11.9

Upper curve, up-stream from the crest.

The origin 0 of abscissas is 34 mm. from the crest in the five experiments.

Crest.	280.6	308.3	323.0	345.7	388.7
0	285.5	312.1	329.8	352.7	394.6
50	296.3	320.0	338.0	362.2	404.8
100	301.2	328.0	344.6	368.0	414.0
150	307.1	332.5	349.8	375.4	418.3
200	308.8	337.6	355.4	379.1	423.8
250	313.0	339.4	357.8	383.5	427.3
300	. . . .	. . . .	360.3	386.8	. . . .
350	317.4	344.7	366.7	389.5	433.0
450	320.2	347.7	365.6	391.4	437.8
550	320.6	348.5	369.6	394.4	439.1
650	323.8	350.3	369.3	396.4	442.2
750	321.5	351.3	371.3	396.6	443.5
850	320.4	350.5	371.4	398.1	446.0
950	323.8	352.3	372.5	397.7	446.0
1.050	324.3	350.9	374.4	397.3	450 3
1.150	322.6	353.4	371.5	399.4	447.4
1.250	324.0	352.5	374.0	398.3	447.2
1.350	322.8	352.8	374.2	399.7	447.0

VIII.

THE BALDWIN COMPOUND LOCOMOTIVE.

By S. M. Vauclain, Active Member of the Club.

Read February 18, 1893.

In presenting the subject of The Baldwin Compound Locomotive, Vauclain System, to the members of the Engineers' Club of Philadelphia, I wish to call attention to the fact that there are quite a number of types of compound locomotives in existence, running with varied success. The difficulty to overcome in constructing compound locomotives is so to arrange the machinery that the repairs in service will not exceed those made to the single expansion locomotive to an extent to offset any economy in fuel consumption.

The necessity for economy on railroads has at last reached the coal pile, and it is wonderful what saving can be effected in that direction by the compound locomotive, not only directly, but indirectly, as its introduction has caused every railroad master mechanic to put his single expansion locomotives in the best possible shape, and compels the compound locomotive when on trial to compete, not with the average, but with the very best single expansion locomotive on the road.

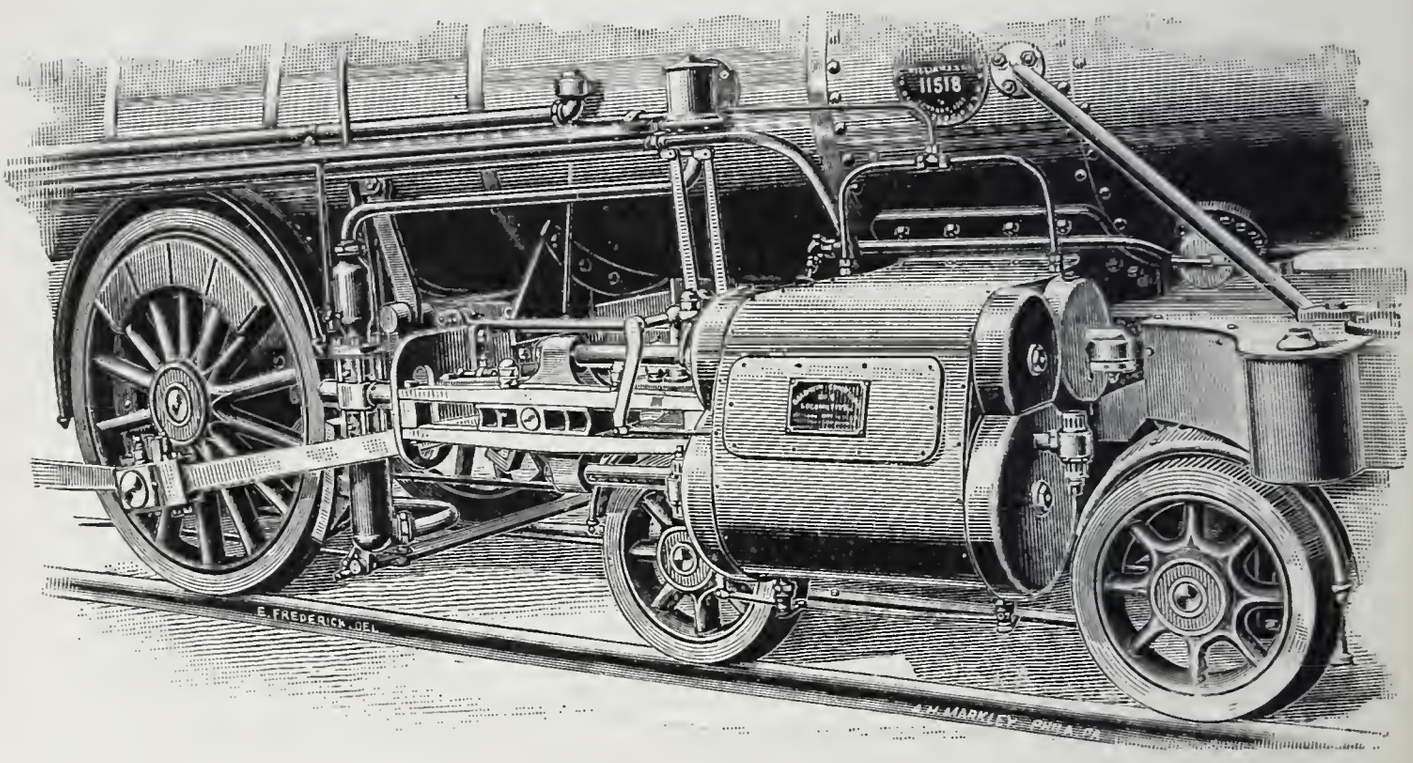
The compounding of locomotives has been practiced by several prominent mechanical superintendents in Europe, most notably Messrs. Wordsell, Von Borries, Webb, LaPage, Wolfe, and Mallet; but, strange to say, none of these eminent men were of the same mind, as their patents differ not only in type or system, but also in the details of construction. With nearly a score of years in which to develop the compound locomotive, and the advantage they possessed for the introduction of their various designs or inventions, the year 1889 found the compound locomotive yet in its experimental stage in Europe.

Americans were watching all these improvements, and while some were willing to take up the struggle that their European friends were becoming tired of, others were busy devising something entirely new and strictly American, that would come to the rescue of the cause, and establish firmly the fact that compound

locomotives can be so constructed that they will be more economical in every way than the single expansion locomotive that has been our friend and sole reliance for sixty years.

It remained for the Baldwin Locomotive Works—the oldest and most celebrated locomotive works in the world—to bring out, perfect and firmly establish the only American type, and the most economical compound locomotive. Just four years ago the writer was fortunate enough to conceive the idea and design the first four-cylinder and ideal engine, as shown by Fig. 1, for which patents were obtained; but the rapid development of this

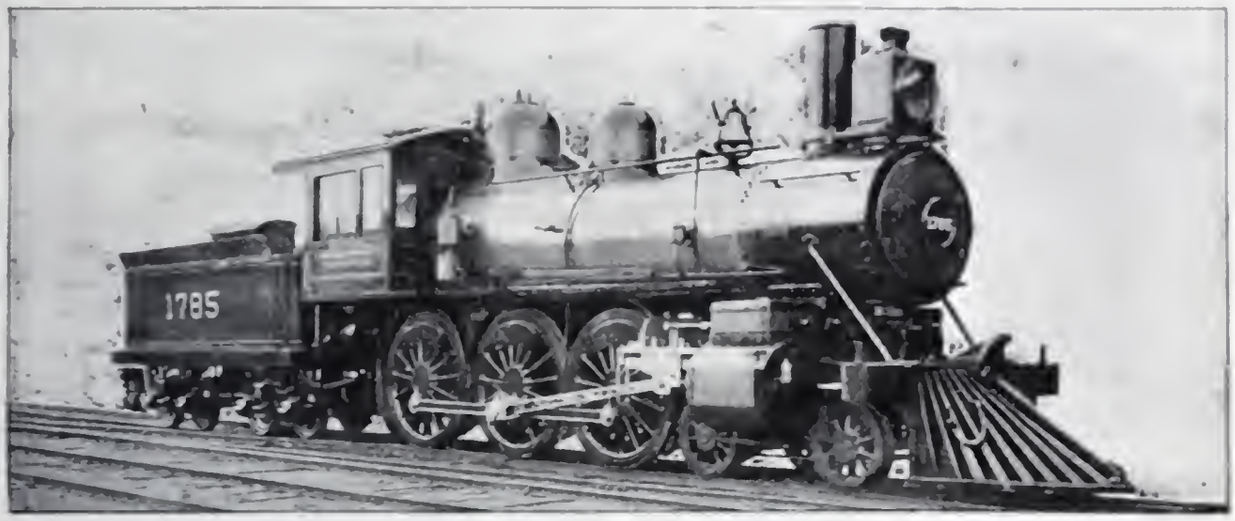
Fig. 1.



system is due to the brains and experience of the entire Baldwin Locomotive Works as a unit. No one man can accomplish such achievements as have been accomplished during the past four years. The personal pronoun must be obliterated if the world at large is to be benefited by a radical improvement in locomotives.

Before going into the subject, allow me to show a few of the most effective types of compound locomotives constructed prior to the origin of the Baldwin. The locomotive shown in Fig. 2 was built by the Schenectady Locomotive Works of Schenectady, New York. It is known to locomotive people as the two-cylinder type. It is this particular type that has on account of its *apparent*

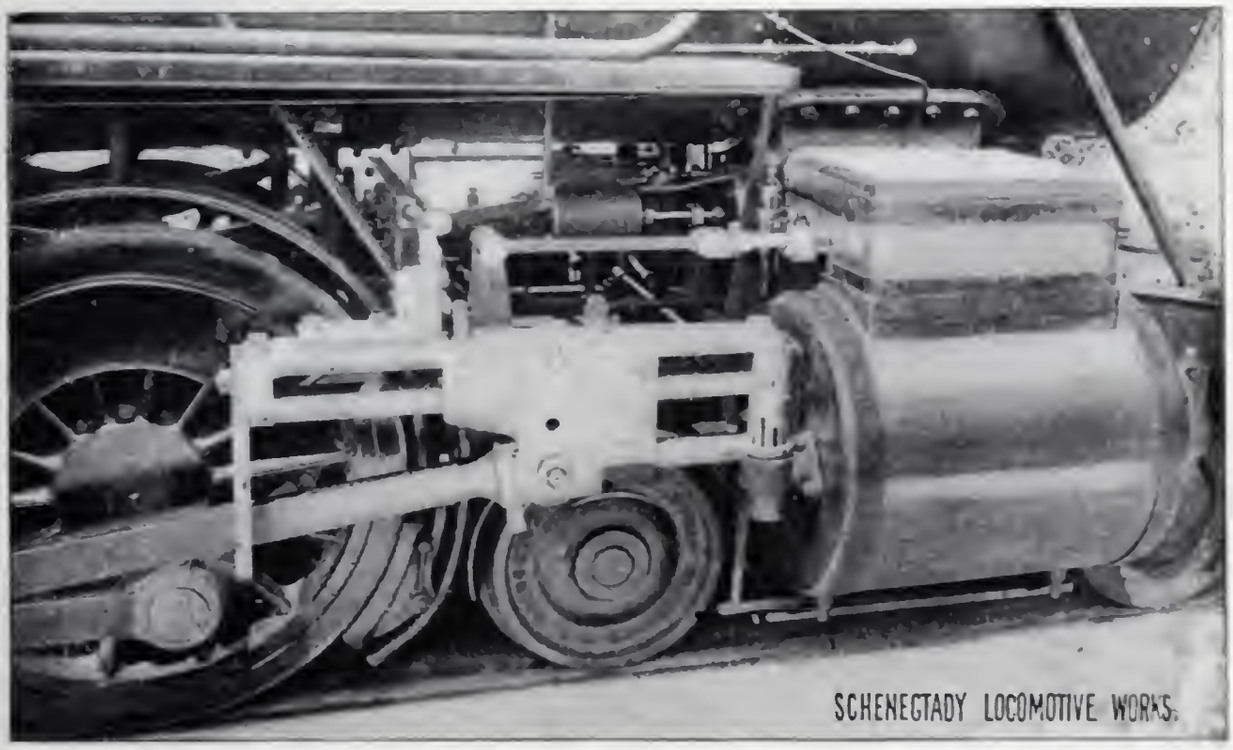
Fig. 2



simplicity beguiled so many inventive mechanics into an attempt to perfect it. Does it not appear to you that if once perfected, it would be accepted, and no more brain power wasted? The trouble is this: In order to make this type at all serviceable, too much complication of parts and auxiliary mechanism must be added, as shown by Fig. 2 A, so much so that the economy obtained, if any, disappears in the maintenance.

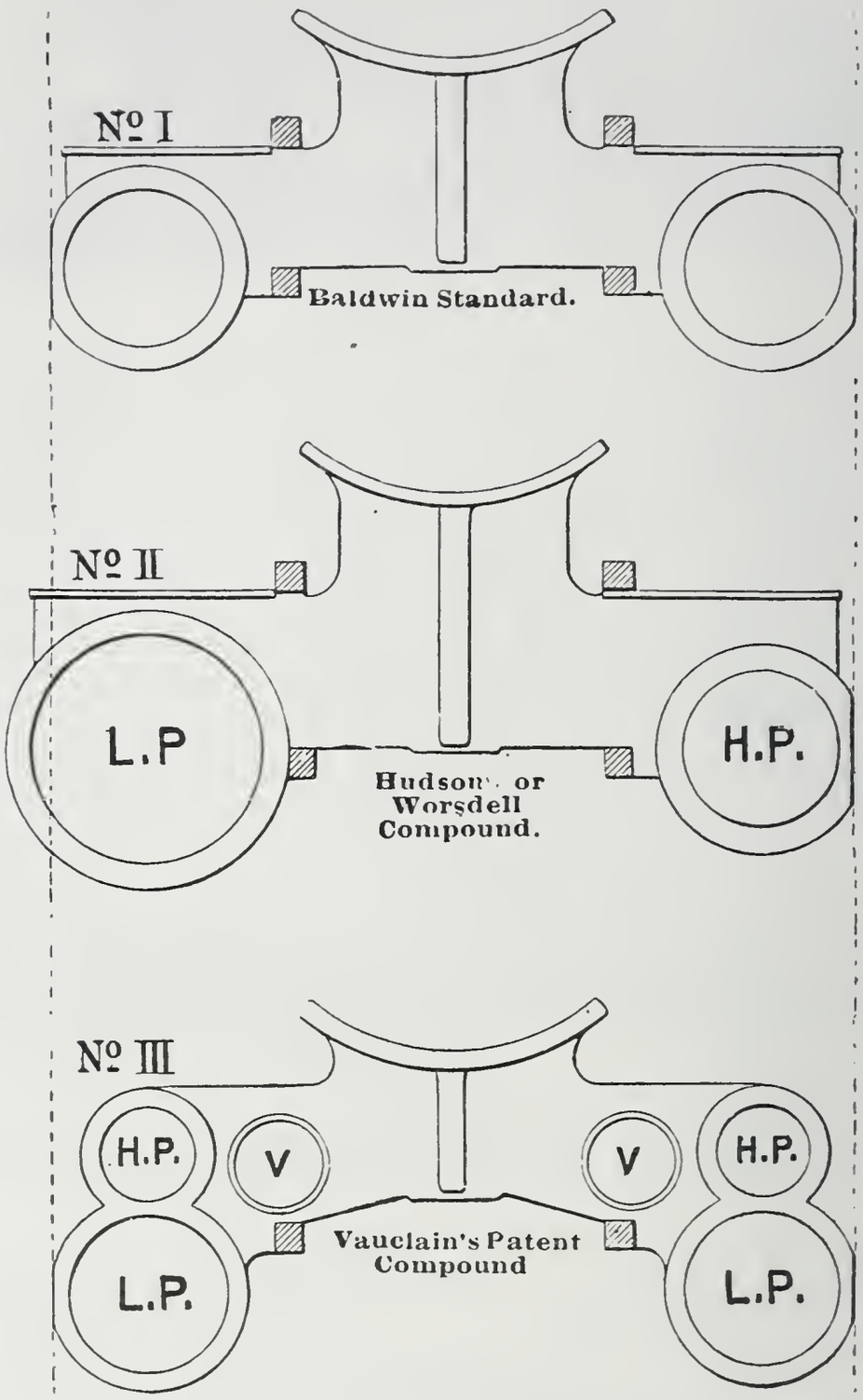
The limit of width on most all railroads limits the size of the locomotive, and many of our largest engines could not be con-

Fig. 2a.



structed on this plan. Figure 3 will show clearly how and why this is so. The cylinders as drawn were for a moderate-sized locomotive and not for the larger and more powerful locomotives now in demand.

Fig. 3.



It is impossible to get a proper distribution of steam and consequent equalization of power, causing an unevenness of motion very injurious to the locomotive. This locomotive is also somewhat like a balky horse. It fails at times to start, due entirely to

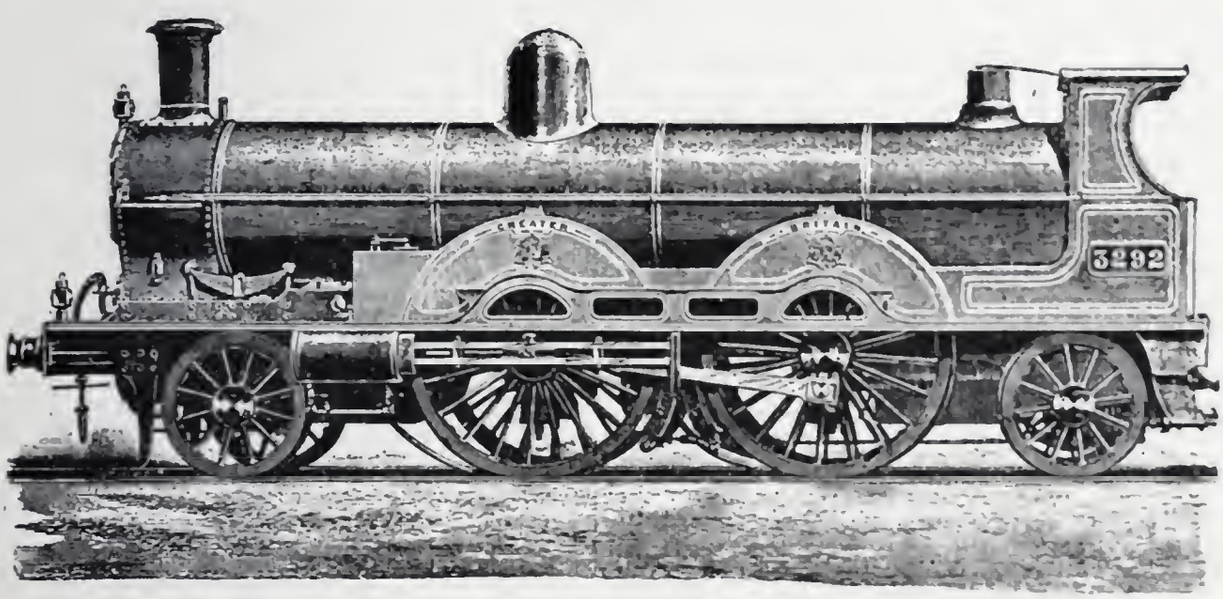
its one-sided construction and failure of the internal mechanism to properly perform its functions.

It must also be understood that hundreds of these locomotives have been built, but almost entirely by mechanical superintendents for use on their own roads. Some of you may understand how very much easier it is for you to build machinery for your own use, than it is to satisfy your customers.

It remained for Americans to build this type of compound locomotive and offer it for sale upon its merits. This has been done by the Schenectady and Rhode Island Locomotive Works, while the Brooks, Pittsburgh, Rogers and Cooke Locomotive Works have experimented, as also have the Chicago, Burlington and Quincy, Lehigh Valley, Old Colony and Pennsylvania Railroads. The data relating to trials of these engines is difficult to obtain, and for that reason we have taken as a basis the fuel economy of the Worsdell-Von Borris two-cylinder compound, which runs as high as 18 per cent.

The immense advantage a mechanical superintendent of a railroad has in the way of introducing a patented device, is shown by the great number of compound locomotives built upon the Webb system, an example of which is shown in Fig. 4. Two

Fig. 4.



high-pressure cylinders coupled in action with one pair of driving wheels, and one low-pressure cylinder coupled in action to another pair of driving wheels, with no connecting rods between the driving wheels, forming practically a locomotive with two single pairs

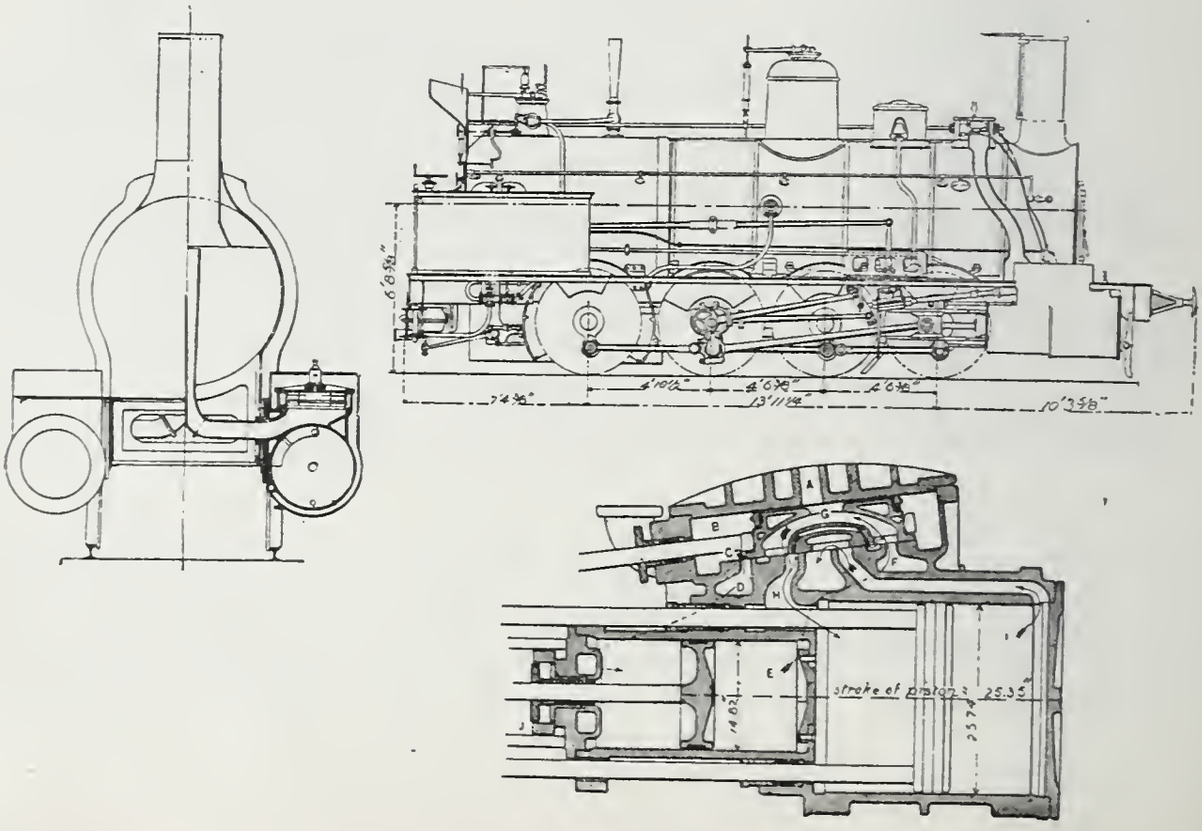
of driving wheels. These locomotives have been built in great numbers for the London & Northwestern Railway, but meet with little favor elsewhere; this type is accredited with giving better satisfaction in England than its rival, the two-cylinder compound.

Mr. Clement E. Stratton, in his new work "The Locomotive and its Development," says, concerning English compound locomotives of the two types already described, as follows: "The writer has watched the subject most carefully from the first, in an impartial spirit, but he can not fail to observe that 'facts' are in favor of the 'simple' engine, (meaning single expansion). Whatever a compound engine can do a 'simple' can do, and frequently with more efficiency. It is therefore not a matter of surprise that the locomotive superintendents of all the other important lines, after having made themselves fully acquainted with the compounds in use in this country, continue to build large numbers of non-compound express engines which give great satisfaction."

It is to be understood by this statement that compound locomotives as made and used in England do not give as good results as the single expansion locomotives. This statement may explain the extreme cautiousness of the railroads in this country using two cylinder compound locomotives.

Another type of compound locomotive, and one that has given good results, is the Tandem, that shown in Fig. 5 being a Wolfe;

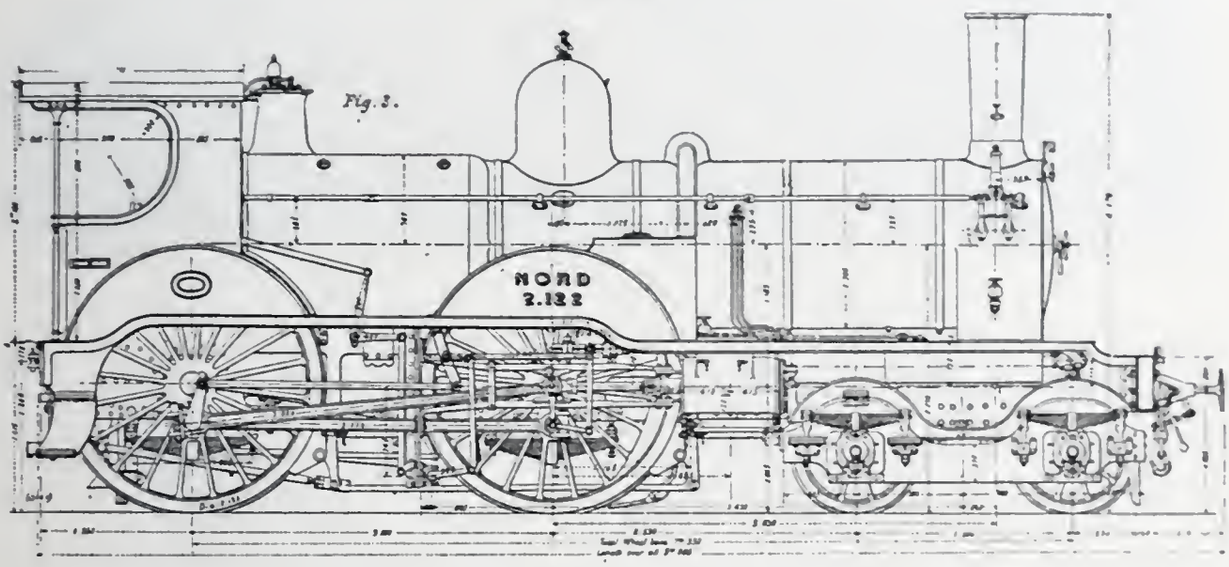
Fig. 5.



a few of them have been built, but the weight and complication of parts prevents its more general introduction, although some one seems bold enough from time to time to build one or more of them with a view, no doubt, of overcoming some of the chief objections. The Brooks Locomotive Works have recently constructed a compound locomotive on this plan and have it in successful operation on the Great Northern Railway.

The locomotive shown in Fig. 6 will give you an idea of the

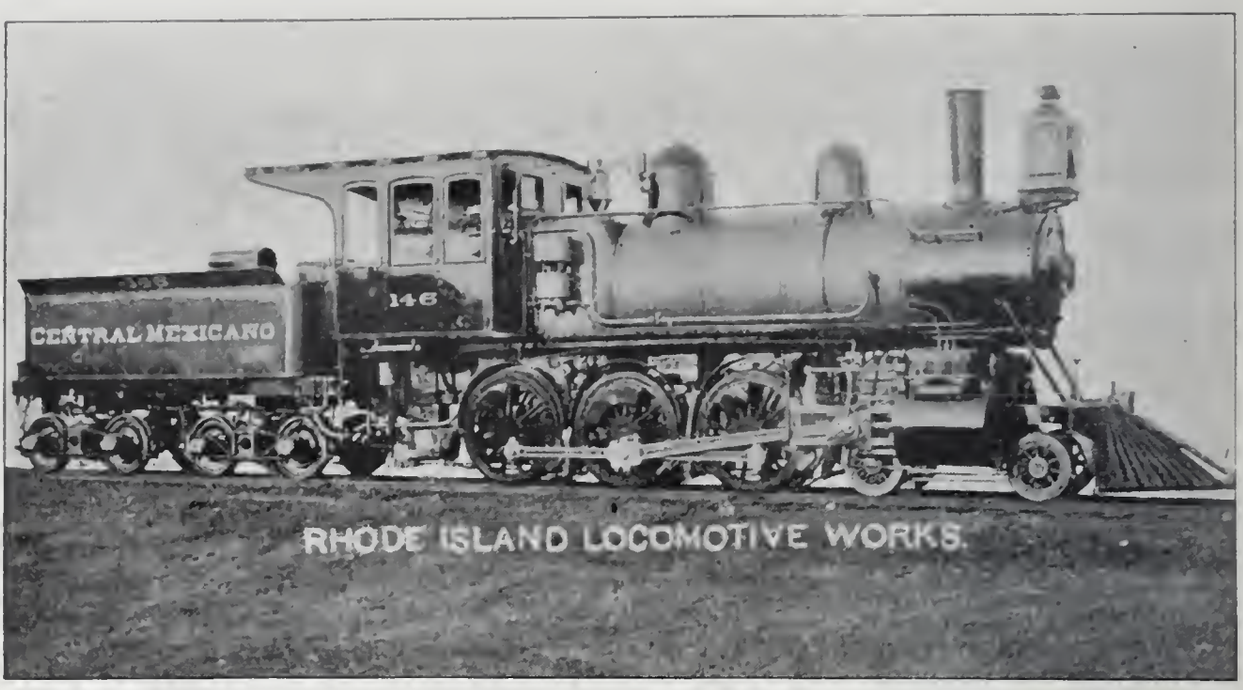
Fig. 6.



four-cylinder locomotives used in France on the Northern Railway. The cylinders are separate and necessitate a complete duplication of parts, also the use of crank axles, but notwithstanding all this additional mechanism I am led to believe them to be the most successful compound locomotives in all Europe to-day.

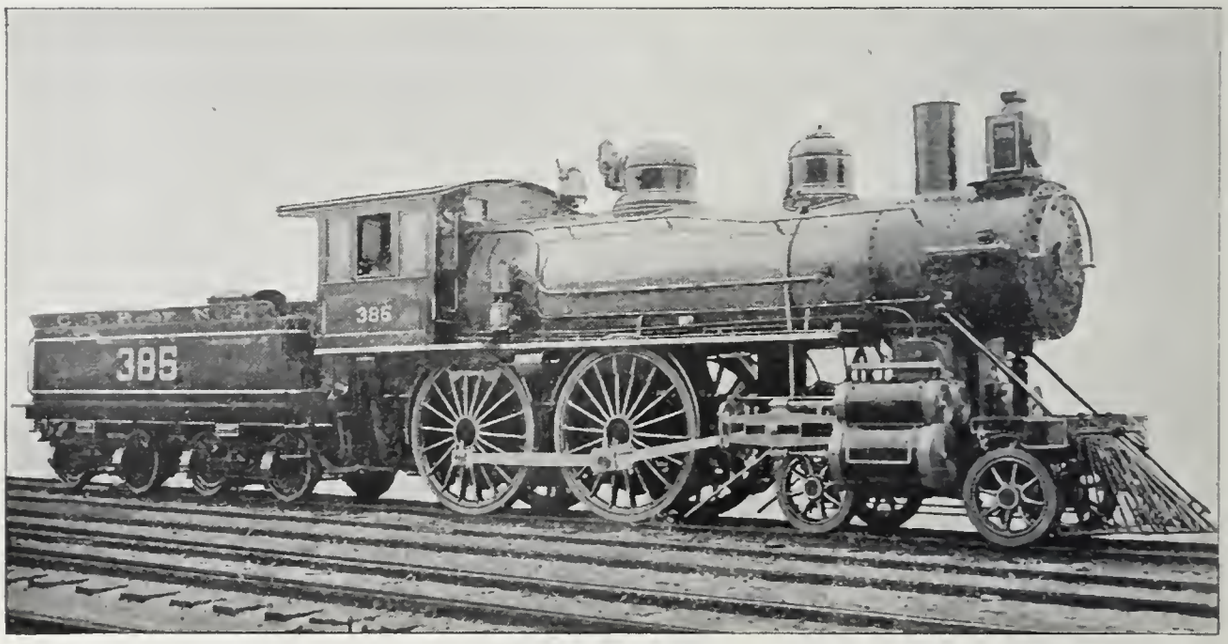
Figure 7 shows another of the four-cylinder species and consists of one cylinder inside another, the high-pressure cylinders being inside the low-pressure cylinders. The arrangement of the cylinders is old, steam pumps of this design having been exhibited at the Centennial Exhibition, and no doubt seen there by many of you here present. This locomotive is patented by Mr. Johnstone, S. M. P. of the Mexican Central Railway, and although its peculiar construction causes considerable complication, a number of them have been introduced on the Mexican Central Railway, and it is said show considerable fuel economy at slow speeds. Mr. Johnstone's patents cover the slide valve only, the arrangement of the cylinders being old.

Fig. 7.



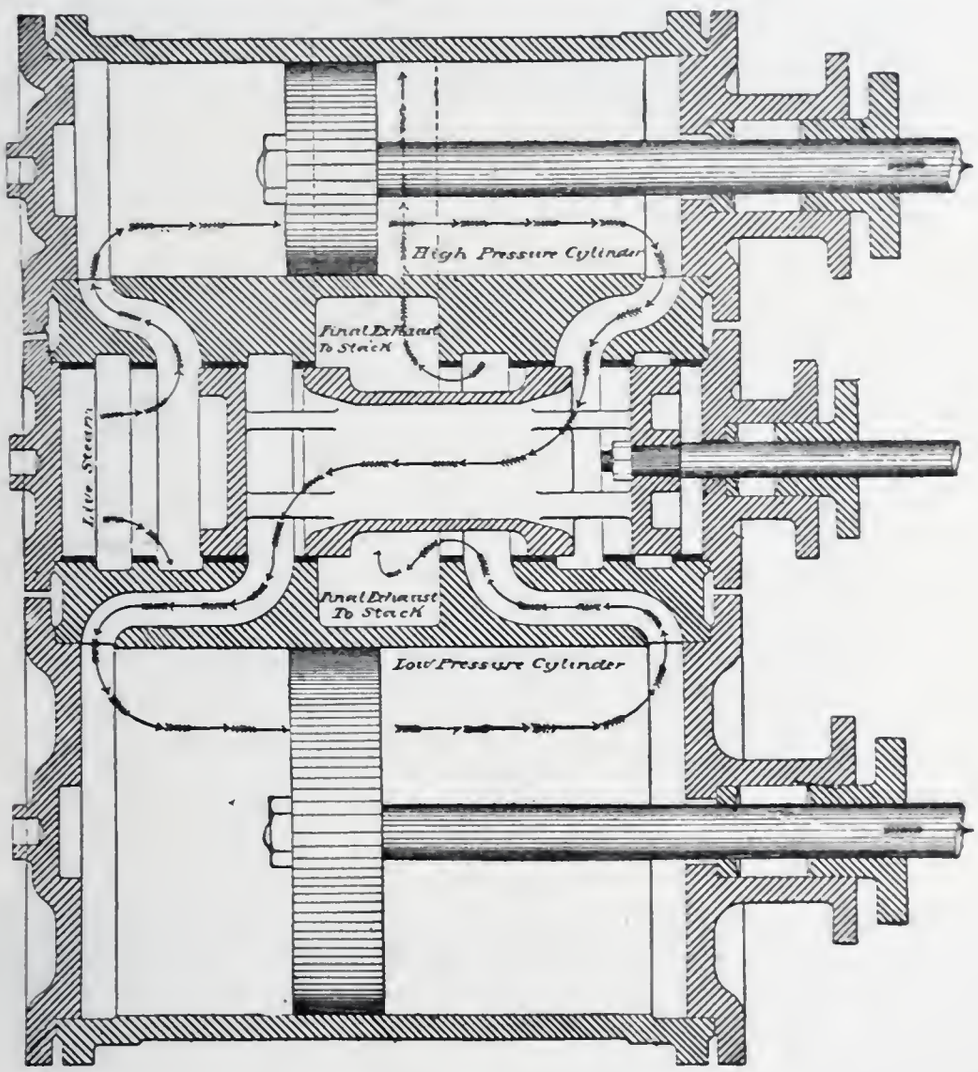
And now we come to the only American compound locomotive (Fig. 8), patented by the writer and designed and built in great numbers for their customers by the Baldwin Locomotive Works. It is this particular type of compound that has made the compound locomotive the locomotive of the future. The infirmities of many of the different types already brought to your attention will henceforth be borne with, and a general introduction of compounds in their several varieties is sure to follow the already established demand for the Baldwin Four Cylinder Compound Locomotive.

Fig. 8.



Its peculiarity is that the high and low pressure cylinders are cast together, are parallel and placed vertically one above the other as may be desired, the supply and distribution of steam of both cylinders being governed by one valve working in a steam chest cast solid with the cylinder and half saddle.* Referring to Fig. 9 the end ports are the supply ports, the next from either

Fig. 9.

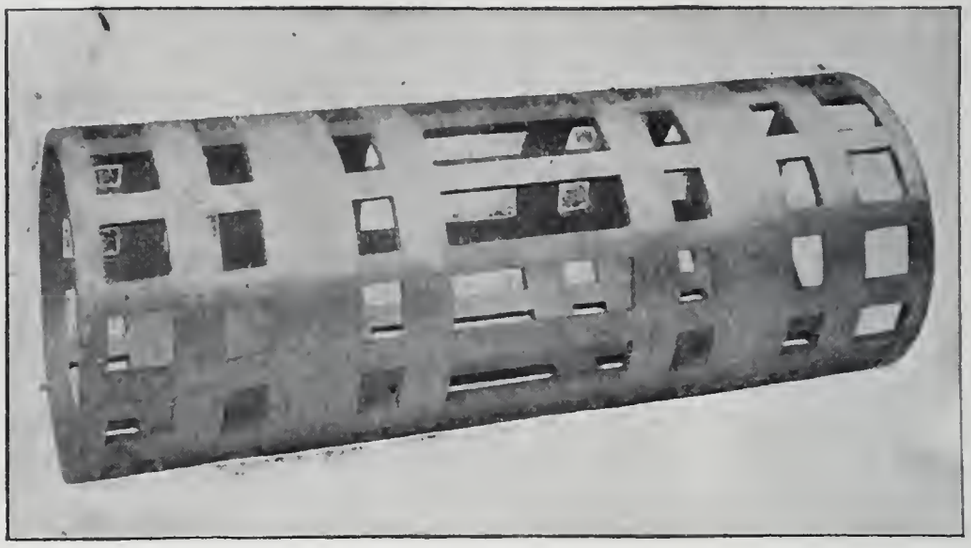


end are the high pressure steam ports, the next are the low pressure steam ports, and the center port the final exhaust.

This valve is not only perfectly balanced, but it is the only valve that can be successfully operated on a locomotive at 200 pounds steam pressure. The friction is scarcely perceptible. The reverse lever can be handled as easily under a full head of steam as where steam is shut off.

* The action of the valve was clearly shown by a moving diagram thrown upon the screen.

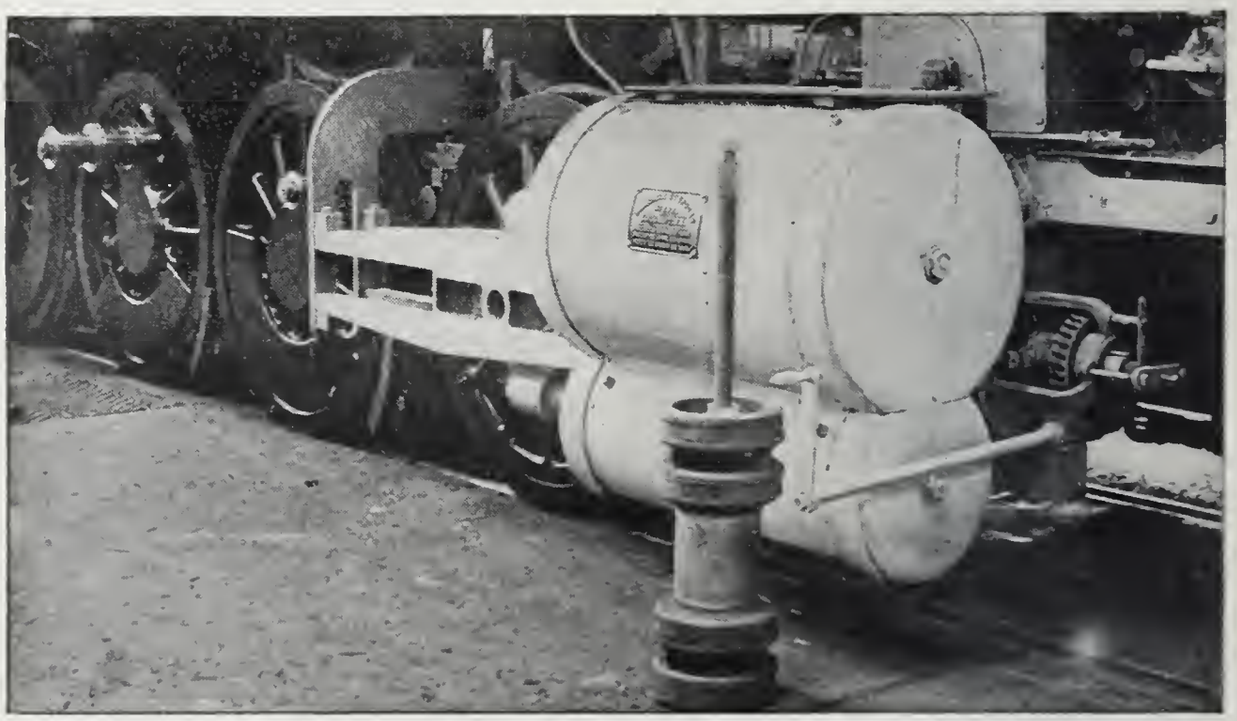
Fig. 9a.



The valve seat, you will notice (Fig. 9 A), is a bushing or sleeve pressed into the cylinder casting. It is accurately fitted and made an interchangeable feature of the locomotive, and when worn out can be replaced in a few hours at a trivial expense, thereby making the valve seat more durable than the cylinder itself Many cylinders on single expansion engines are replaced on account of the valve seats wearing and false seats failing.

In case the valve seat becomes cut and it is thought best to true it up in position, I have designed for this purpose a special boring device (as shown in Fig. 10) which is partially self-adjust-

Fig. 10.

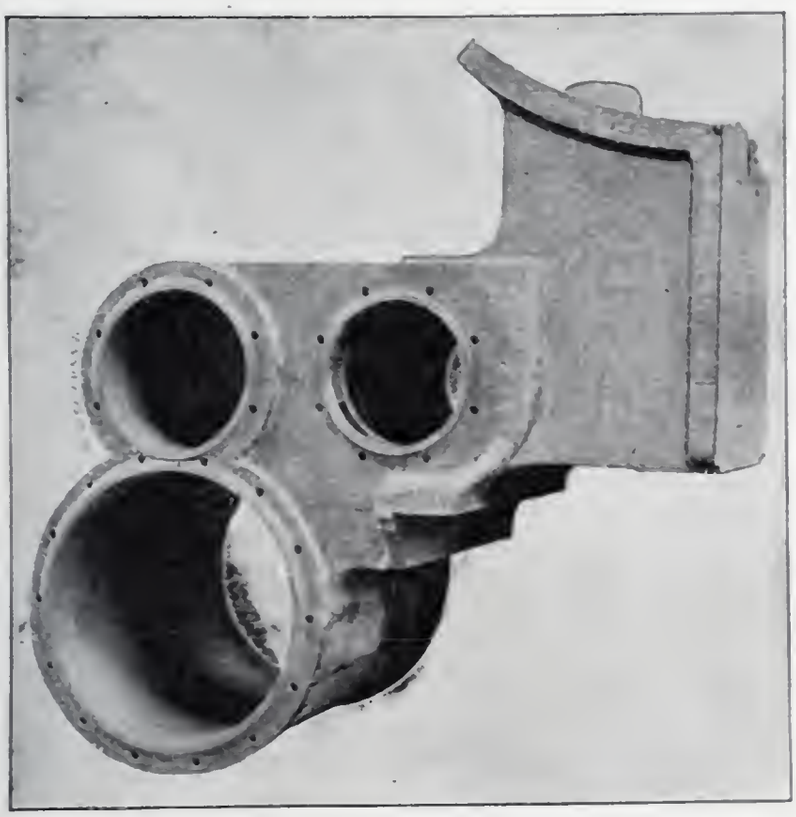


ing and does away with removing the back head of the steam chest. The front head is removed, the valve taken out and the bar put in from the front end, fastened, and the operator can, in a few hours, true out the bushing. The operation can be done in less time than it takes to face the valve seat of the single expansion locomotive, or in fact any slide valve seat.

It is the use of the piston valve, its absence of friction, its splendid distribution of steam, that makes the Baldwin Compound Locomotive what it is and especially adapts it to high pressure and high speeds.

Another advantage in this type of compound is that both sides of the locomotive are the same, as shown by Fig. 10 A, thereby

Fig. 10a.



equally dividing the power. All the patterns answer for either side. The smoke box and its contained mysteries, cylinder saddle, frames, valve motion, and in fact everything except the cylinders, cross-heads, guides and piston valves, are precisely the same as on single expansion locomotives.

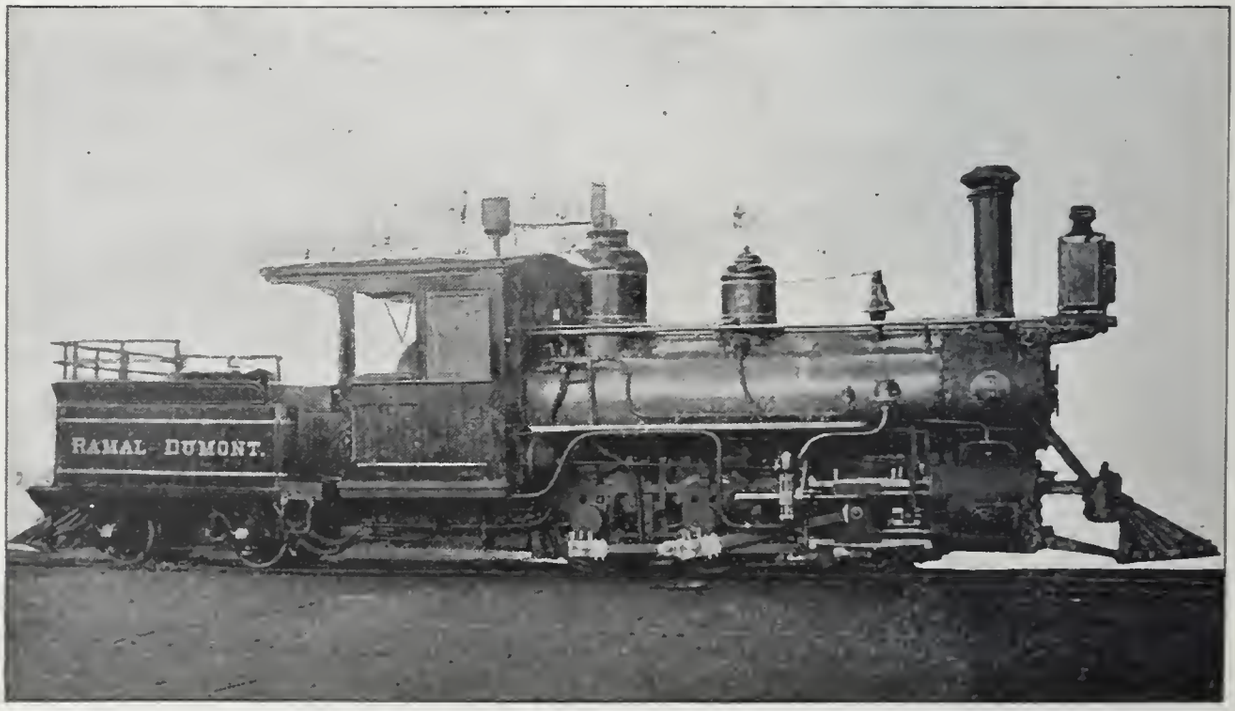
We are enabled by this system to compound the largest locomotives built, the one shown on the canvas, Fig. 11, being

Fig. 11.

one of six for the New York, Lake Erie & Western R. R. The boiler is 76″ diameter. Total weight of engine, exclusive of tender, 200,000 pounds; and cylinders equivalent to single expansion cylinders 24″ diameter by 28″ stroke. These locomotives do the work of two heavy consolidation locomotives, and by one year's service of this kind have proved their economy and capacity conclusively.

I also take pleasure in showing Fig. 12, one of the smallest

Fig. 12.



gauge ($23\frac{3}{8}''$) compound locomotives. These two locomotives will give you an idea of the range of application. We are able to obtain by this system an economy, efficiency and adaptability not obtainable by any other method of compounding locomotives known to-day.

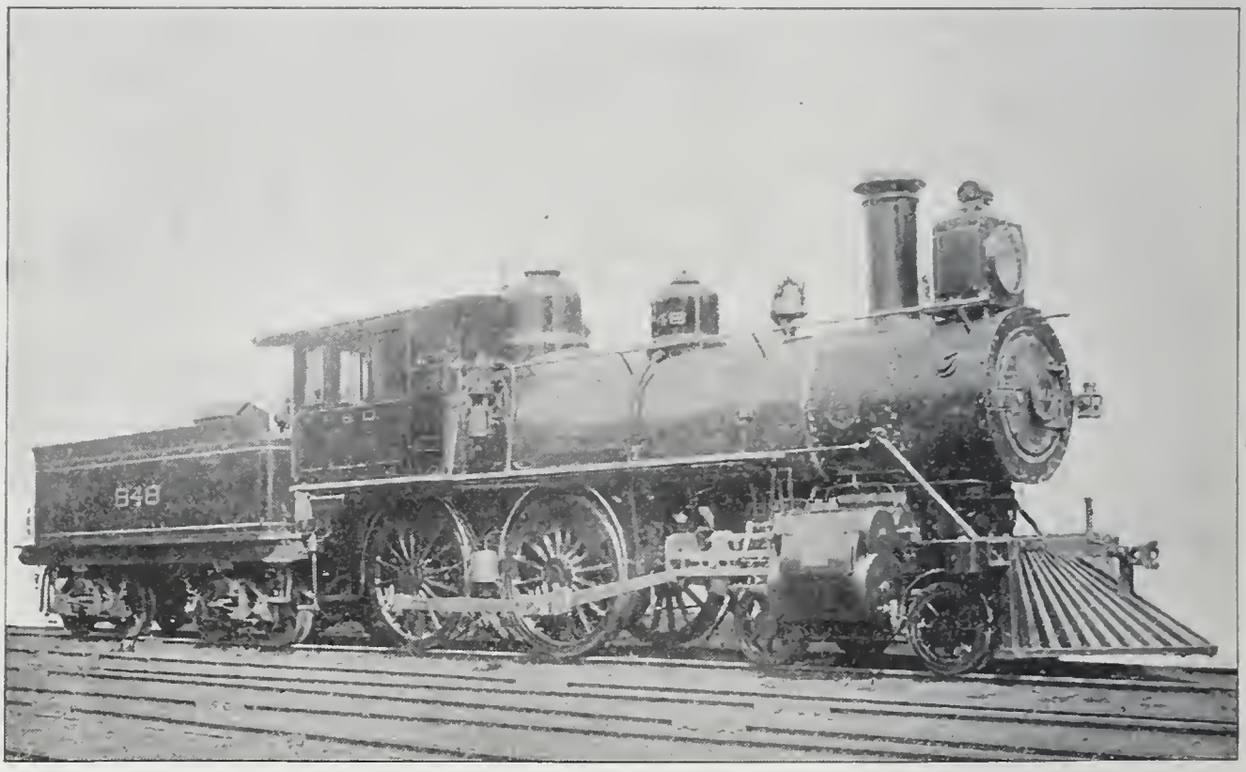
At the last Master Mechanics Convention, I stated that time would prove that our compound locomotive would require *less* repairs than the single expansion locomotives, and by the time of the next meeting I will have ample proof that my expectations at that time have been realized. It has been found that the total cylinder repairs to any locomotive is barely 5 per cent. of the total repairs, and that the boiler repairs is the largest item, also that the boilers of compound locomotives do not require the attention or repairs that are necessary to their overworked comrades. The result is that several master mechanics now declare that the Baldwin Compound Locomotive is not only very economical in the use of fuel, but costs less for repairs while in service. This has been especially noticeable on the M. K. & T. R. R., where alkali water is used. The tubes of all the single expansion locomotives delivered at the same time the Compound in Fig. 13 was sent them, have been recaulked and in several cases removed entirely, whereas up to the present time the Compound has had no work done to the boiler at all.

Fig. 13.

I might add that these locomotives are all on the same division, in the same service, and running constantly, except when laid up for repairs. The compound also shows at the same time a fuel economy over all engines of her class of 36.6 per cent.

The rapidity with which this type of Compound has gained favor, and overcome the opposition of those who thought it would not be a success, and has developed a demand for itself, is simply remarkable. In the year 1889, we built the first one as shown in Fig. 14; we employed one of the best steam experts in

Fig. 14.



the country, Mr. Geo. H. Barrus, of Boston, to test this locomotive in an impartial manner, and report to us whether it posessed merit, and if so, how much. His report stated that we could expect a fuel economy of 15 to 35 per cent., suggested certain changes in the steam passages, and that as a locomotive it was all that could be desired.

We had, however, undertaken the construction of other compounds while the trials Mr. Barrus was making were in progress, and in 1890 built the second, third and fourth locomotives going to Brazil, Mexico and Northern Pacific railways respectively. On these engines, the steam ports were proportioned as our ob-

servation directed. In 1891 the boom set in, and before its close we built 83 four-cylinder compounds, making a total of 87, going to all parts of the world and working so satisfactorily that duplicate orders came in very rapidly, as well as orders from other railroads, to such an extent that in 1892 we built no less than 212 four-cylinder compounds, a total of 299 up to January 1, 1893. At this writing over 300 of these locomotives are in service. We have orders for 100 more for spring delivery, and at present compound locomotives comprise about 40 per cent. of the business of an establishment having a capacity of 1,000 locomotives per annum.

It may be truly said the experimental period of the Baldwin Four Cylinder Compound Locomotive has passed. We have built the largest, the smallest and the fastest locomotives in the United States, or in the world, and all on this system.

A locomotive that will develop an indicated water-rate of 16.29 pounds per horse-power per hour, is sure to succeed even though a speed record of over ninety miles per hour may not attract attention.

The following illustrations, Figures 15 to 19, show a few locomotives of this type: First, Figure 15, the Chicago Elevated. Twenty of these locomotives were built and put in operation. After three months service they were condemned by the editor

Fig. 15.

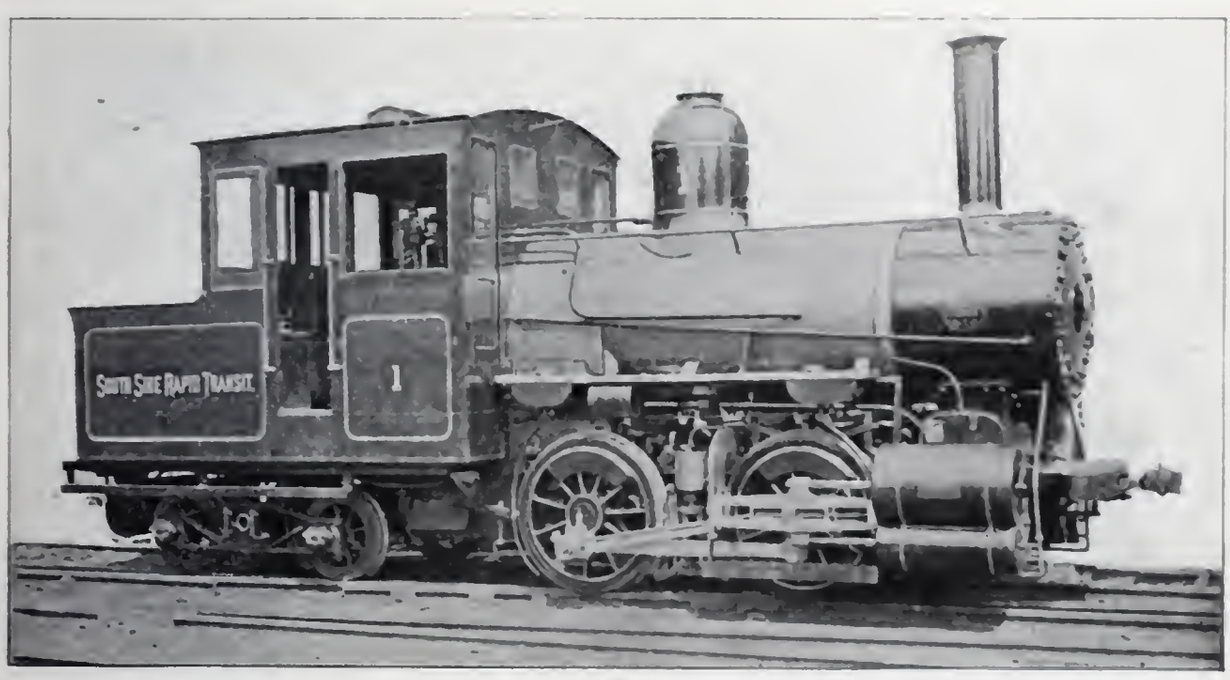


Fig. 16.

of "Locomotive Engineering," and *three days thereafter* were adopted by the railroad company as their standard locomotives, ordering twenty-five additional, exact duplicates, and since their delivery twenty more.

Fig. 16. Philadelphia & Reading Flyer. These locomotives are making speeds of over ninety miles per hour every day. They are the most satisfactory anthracite coal burning locomotives in existence. Five of these locomotives have been in service one year, and sixteen more have been ordered for spring delivery.

Fig. 17.

Fig. 18.

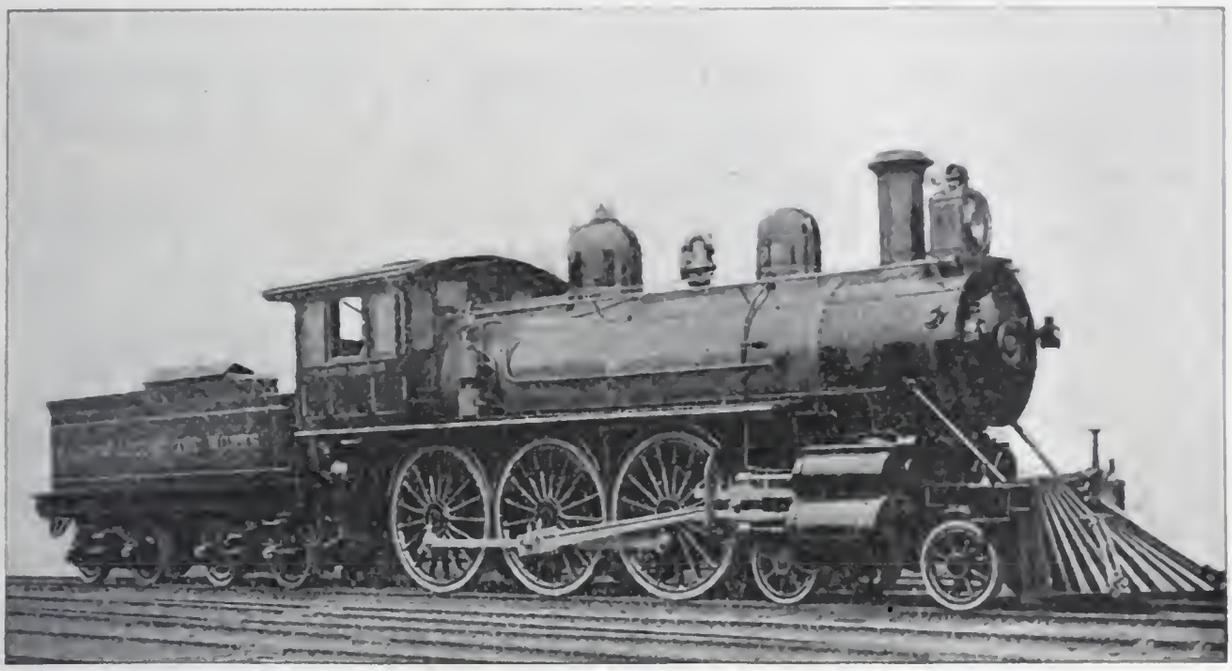
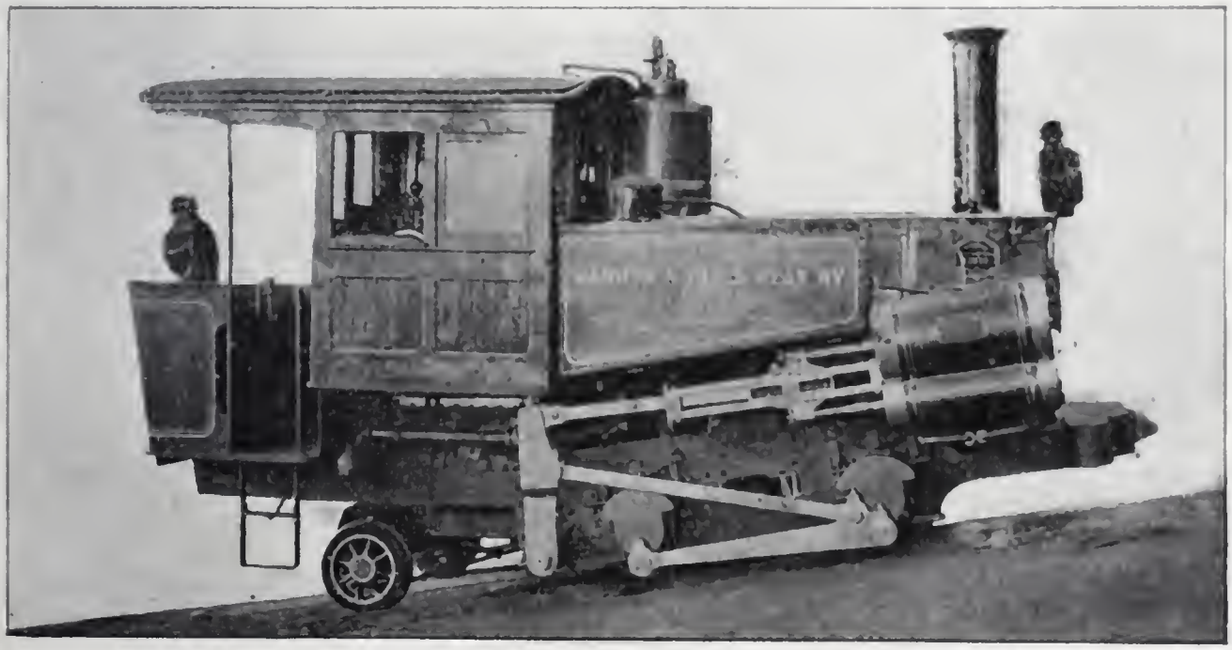


Fig. 17. Heavy consolidation for burning culm or anthracite refuse. The mild exhaust due to this method of compounding, makes this a most satisfactory locomotive for this purpose. The Philadelphia & Reading R. R. Co. has no less than seventy-eight locomotives already built and under construction of this kind, compounded on this system.

Fig. 18. Heavy express locomotive, wheels 72″ diameter. This locomotive has hauled the same trains as a 20″ x 24″ consolida-

Fig. 19.



tion locomotive, and has made speeds of seventy-seven miles per hour in passenger service. It has taken the Pennsylvania Limited Express over the Allegheny Mountains by itself and has brought numerous orders for compound locomotives to the Baldwin Locomotive Works.

The locomotive shown in Fig. 19 was built for the Pike's Peak Rack Railroad, of which you are no doubt familiar. Three single expansion locomotives had been built and were in operation, but the grade being nearly nine miles long, and varying from 16 to 25 per cent., considerable time was consumed in making the trip, not so much on account of the inefficiency of the machine itself, but on account of the numerous stops for fuel and water. When the road needed more power, compound locomotives were looked into and the Baldwin Locomotive Works built for the Manitou and Pike's Peak Railway the locomotive shown. It is, I believe, the first locomotive of its kind in the world. Its performance was very satisfactory indeed. It not only showed a fuel economy, but its great water economy permitted it to pass water stations at which the single expansion had to stop. The fuel economy was about 35 per cent., and the time required to make the trip to the top of the peak was reduced from two hours and thirty minutes to one hour and thirty-five minutes. The result of one season's use of this locomotive has resulted in the railroad company sending all their single expansion locomotives to the Baldwin Locomotive Works to be changed to compounds.

Our compound locomotives are in use on sixty-eight different railroads of the world, many have returned to us the percentage of economy they have been able to obtain, among whom are the following:

	Percentage.		Percentage.
Northern Pacific	26	Western Railway of Cuba	27
Western N. Y. & Penna. R. R.	36.2	Philadelphia & Reading	33
Penna. & Northwestern	33	Cinc., N. O. & Texas Pacific	44
Missouri, Kansas & Topeka Railw'y	36.6	Western Maryland	44.9
Norfolk & Western	38	Cornwall & Lebanon	33

We claim a fuel economy of 15 to 25 per cent. in passenger service, and 20 to 35 per cent. in freight service, and not only claim it but will guarantee it to any one purchasing one of our compounds.

Fig. 20.

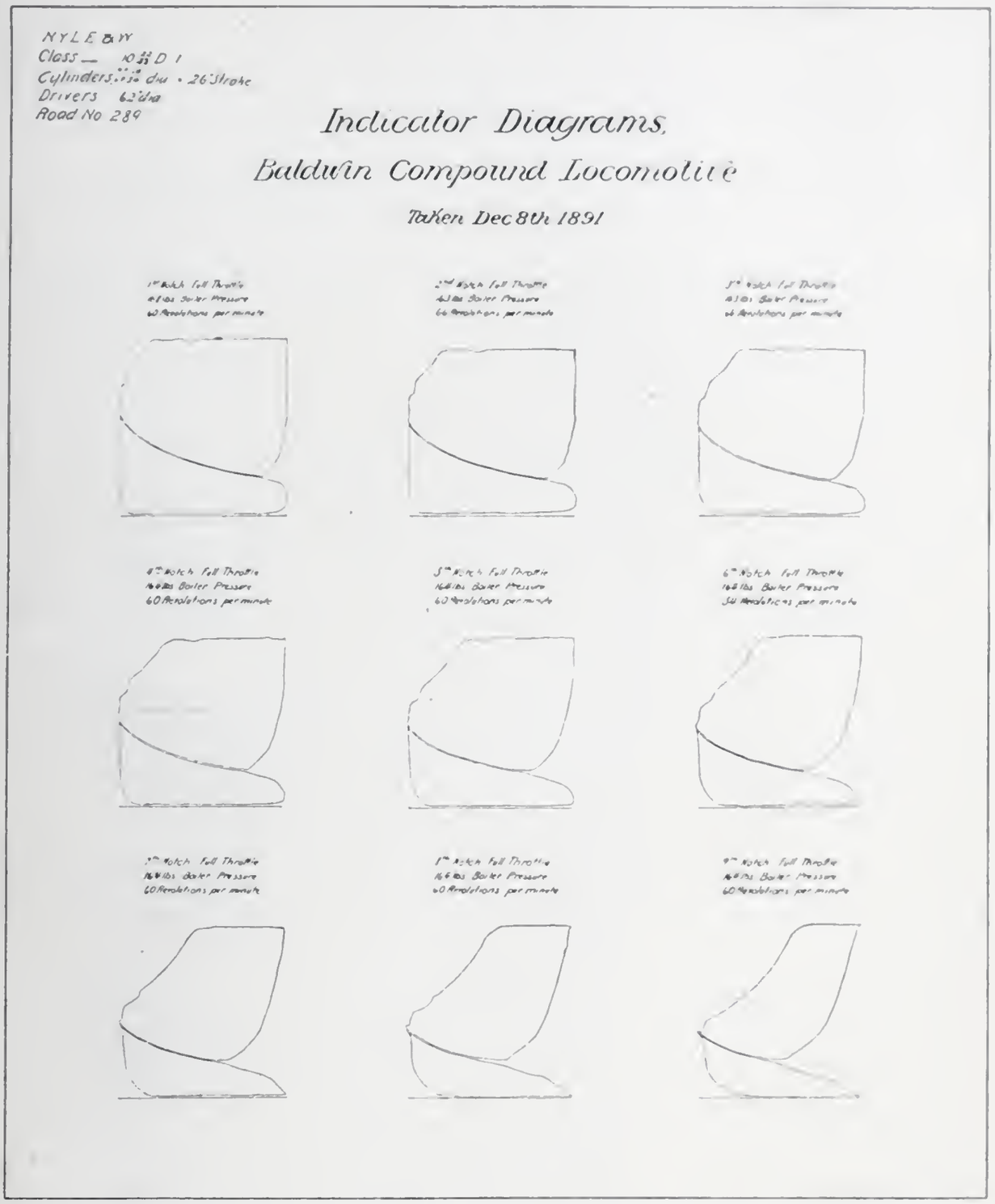


Fig. 20 shows Indicator diagrams taken at each notch on the quadrant, and will give a good idea of the distribution of steam obtained at the several points of cut-off.

Note —The paper was further illustrated by a model working under steam and by a similar model arranged to show the interior construction of the cylinder, and valve chest.

As a matter of interest it may also be added that the merits of the Vauclain system were investigated by the Franklin Institute of Pennsylvania and followed by the award of the *Elliott Cresson Gold Medal.*

IX.

WOOD STRUCTURE IN ITS RELATION TO MECHANICAL PURPOSES.

Abstract of Lecture delivered by Prof. J. T. Rothrock before the Club, March 4, 1893.

The value of wood in the Arts depends usually upon strength, durability, ease of working and abundance.

A closer analysis of the subject might lead one to affirm that, so far as structure was concerned, a piece of wood of a given size, which had the most actual wood in it, was the better. To explain this statement, let us take a single wood fibre of rock elm, and another of common cottonwood, as nearly of the same microscopic dimensions as possible. The former will be not only stronger but heavier. The most evident reason for this is that its walls are thicker and its cavity smaller. In other words, it actually contains more wood than the fibre of cottonwood. In like manner it will be found that, as fuel, the heavier is usually the better wood.

Here then is the first general proposition which may be regarded as approximately true—strength, weight and fuel value are closely related to each other, for the simple reason that they depend upon the same cause.

Specific gravity is due probably quite as much to the quantity of air entangled in wood fibre as it is to difference in the cellulose (making up the woody fibre). The process of water-logging may be mainly the substitution of water for air in the woody tissue.

Looking at a cross-section of hard wood, one will observe lines extending from the center towards the circumference. These are the so-called silver-grain, or the medullary rays. They have two functions, the first being to act as a means of communication between the outside and the inside of the stem or trunk. These silver grains are made up of rectangular cells whose greater axis is horizontal, and hence they would seem to be well fitted, not only to act as means of communication in the direction of this greater axis, but also to act as chains, if one might venture on so crude a comparison, to bind together the outer and inner portions

Scale, 40 to 1.

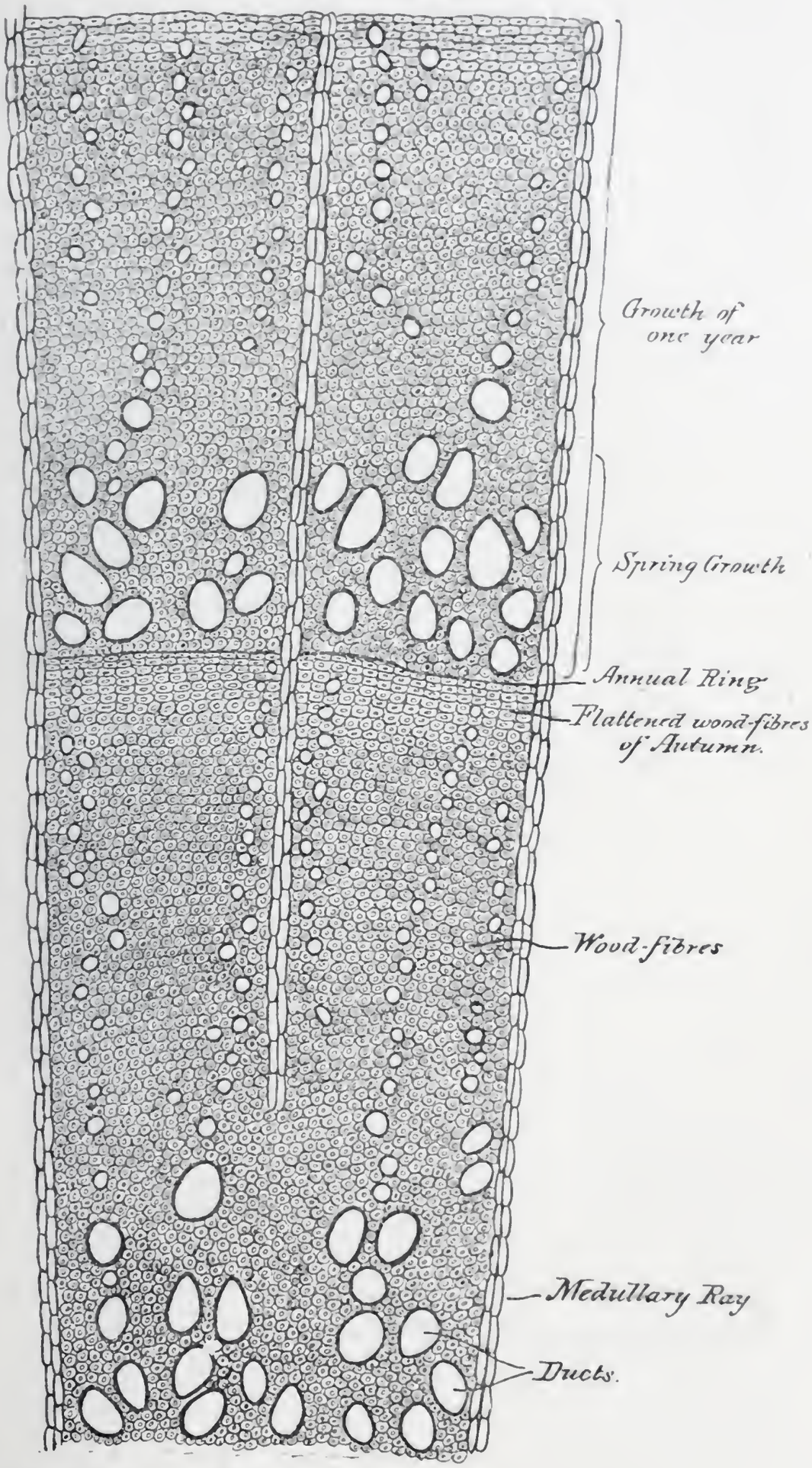


Fig. 1. Quercus Rubra,
Red Oak, Cross Section.

of the stem, whose woody fibre runs in a vertical direction and therefore at right angles to the cells of the silver grain. That this is true, is readily proved by the fact that wood is harder, as a rule, to split at right angles to this silver grain than it is parallel to it. And my second proposition lies in this statement.

Then one more point of structure is plainly visible to the naked eye on examining a cross-section of a woody stem. It is the well-known ring, or rings, constituting the so-called year's growth. This is due to the contrast between the large fibres or ducts formed in the early part of the growing season, and the smaller and more compact fibres of the latter part of the season.

This statement holds good, in the main, for all plants whose annual growth is thus visible on cross-section. It does not follow, however, that there are no differences of structure between them. On the contrary, one may readily detect three types of annual ring. The first and most common one is that represented by the oaks, in which we find the first structural work of the year marked by certain large-mouthed vessels which, on cross-section, show as pores, plainly visible to the naked eye. Whatever else the tree is to produce that season, it always makes these first, and whether the subsequent belt of denser tissue is wide or narrow, that of the ducts or pores varies but little.

As these ducts have thin walls and large cavities, while the fibres, on the contrary, have thick walls and small cavities, it is clear that the ducts are relatively an element of weakness, as compared with the fibres. It also follows that *when one compares two specimens of wood of the same species, having this type of structure, that the larger year's growth will indicate the stronger and the heavier specimen. This, then, is my third proposition.*

The oak, hickory, elm, ash, hack-berry and chestnut may be regarded as representing the above type.

Then there is a second type, represented by the beech, sugar-maple and silver-maple, yellow birch, linden, butternut, wild black cherry, and many others, in which the ducts or pores are almost equally visible in all parts of the year's growth. In such instances weight would be one criterion of value. Another would be relative scarcity of ducts, and a corresponding increase in proportion of wood fibres. And still a third guide (under the microscope) would be the thickness of the walls of the woody fibre.

Scale, 40 to 1.

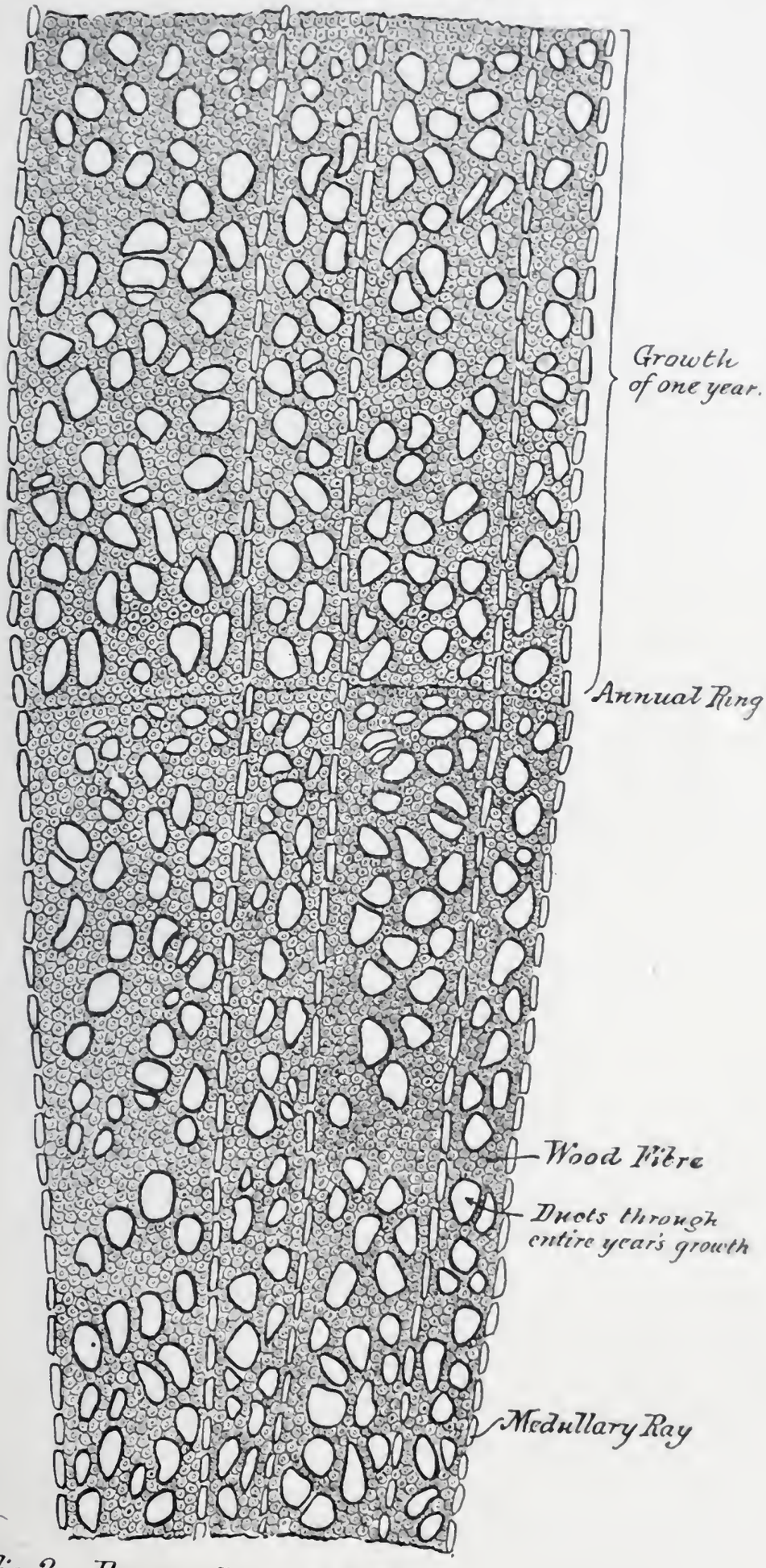


Fig. 2. Prunus Serotina Ehrh.
Wild Black Cherry. Cross Section.

As a rule this second type is more diversified in structure than the first, and also of less value, as a group, for purposes where either great strength or durability is required.

My fourth proposition then is, that where the ducts or pores are visible *over the whole year's growth, that preponderance and thickness of fibre over duct, measures (usually) the value of the wood where strength is required.*

There remains still a third type, which is represented by the cone-bearing trees. The year's growth is usually plainly marked, but there are no ducts or pores visible on cross-section, such as you see in the first type. The few apparent ducts are resin cavities, and of no moment in our present estimate. The whole mass of the solid tissue is made up of more or less modified wood fibres. The only real structural distinction is that the wood fibres (or tracheids) of spring have thinner walls and larger cavities than those of late summer or early autumn. The latter also contain more resin.

It will require but a brief examination to ascertain that the strength of timber in this group is fairly measured by the width of the autumn belt of thick fibres (seen on cross-section) of the year's growth; and this is my fifth proposition.

Concerning this group it remains to be said that lumber from the long-leaf pine of the Southern States has suffered no loss of strength if it comes from matured trees which have been bled for turpentine. The durability of such lumber, however, would *probably* be considerably reduced if used in exposed situations.

It should be stated that too much value has been placed by our Courts on the value of the year's growth as a means of determining the period of time elapsing since the "blazes and witnesses" were made which are supposed to mark the date of a survey. Giving the argument the utmost possible value, there still remains a doubt as to the entire reliability of such evidence.

It should also be remembered that there is a right way and a wrong way of placing a beam, in an exposed position, to obtain the greatest durability. If the year's growth is placed so as to put the convex surface uppermost, each annual ring acts as a roof to those beneath. If placed with the concave side up, the year's growth tends to make a trough, into which moisture will work and so hasten the decay of the stick.

Scale, 40 to 1.

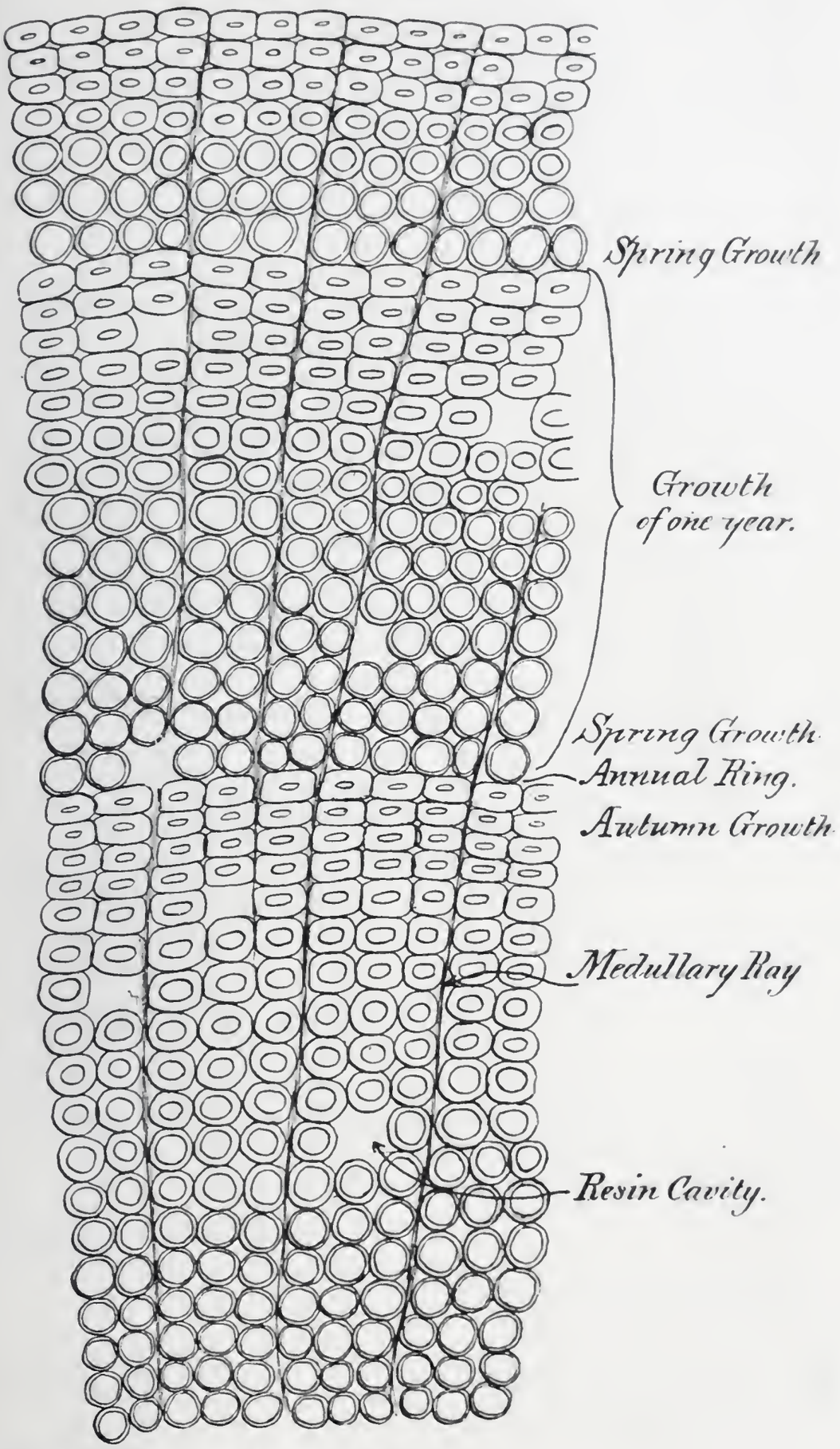


Fig. 3, Tsuga Canadensis, Hemlock Spruce, Cross Section.

ANNUAL REPORT OF THE TREASURER.

For the Fiscal Year, 1892.

Presented at the Annual Meeting, January 21, 1893.

To the Engineers' Club of Philadelphia.

Gentlemen: In presenting the Report of the Treasurer for 1891, it was impossible to give anything more than a mere outline of the condition of the Club's finances, owing to the unsystematic manner in which the accounts had been kept. In presenting the accounts for 1892 we are still hampered by the effects of this, though in a very much less degree. We can however, state accurately just how much money has been received and spent, and how much has been spent on each particular item of the Club's expenses.

After straightening out the worst of the confusion, it was decided by the Board to close the old accounts and to start a new set of books, dating from September 1st, and we are now in a position to state at last, precisely how we stand at the end of 1892 as regards our assets and liabilities. The arrangement of accounts in these books will enable us not merely to know at the end of 1893 what we have received and expended, but at the end of each month, exactly what we have received from initiation fees, dues, both resident and non-resident, advertising, sales of Proceedings, and any other sources; and to know exactly what it has cost us for rent, house expenses, printing of Proceedings, the expenses of the Secretary's Office, including the printing of notices, abstracts, etc., entertainments, purchase of new books, salaries, etc. This will enable us to decide at just what point and to what extent it will be either necessary to economize or allowable to expend.

The receipts for 1892 were as follows:

Cash balance January 1, 1892	$923 02
Received during the year from dues and initiation fees, including all back dues collected	3854 00
Received from advertising, including all old accounts collected	1067 50
Received from sales of Proceedings, including all old accounts	329 83
Subscriptions to Chicago World's Fair Fund	18 00
Received from all other sources, including special subscriptions	184 75
	$6,377 10

Our expenditures during the same time have been:

Salaries:		
Secretary	$566 66	
Treasurer	130 00	
Janitor	300 00	
Stenographer	495 00	
		$1491 66

House Expenses:		
Rent	$1,000 00	
Coal	116 50	
Gas	139 50	
Ice	23 61	
Wanamaker's bill (mostly for furniture, for card and chess-room)	207 28	
Loflin's bill for repairs (new vestibule door, shelves in Secretary's office, etc.)	71 63	
Thompson's bill for plumbing	29 40	
Sundries (small repairs and supplies)	151 11	
		$1,739 03
Luncheons		366 50
Printing		1,568 05
Lithographs, cuts, etc., for Proceedings		176 11
Postage on Proceedings		190 20
Postage, (Secretary's and Treasurer's offices)		122 76
Telephone		128 67
Typewriting Machine		95 00
Sundry small supplies for house and Secretary's office		116 52
Howard Murphy (Reception Account)		83 36
Total expenditures in 1892		$6,077 86
Cash balance January 1, 1893		$299 24

Of the above the following special bills and expenses were incurred previous to January 1, 1892:

Salaries for services rendered in 1891:		
Secretary (Mr. Murphy)	$466 66	
" (Mr. Trautwine)	50 00	
Treasurer	90 00	
		$606 66
Wanamaker's bill	207 28	
Loflin's bill	71 63	
Thompson's bill	29 40	
		308 31
Telephone	128 67	
Typewriting Machine	95 00	
Howard Murphy (Reception Account)	83 36	
		307 03
Total special expenses incurred prior to but paid in 1892		$1222 00

It should be noted that the purchase of the typewriting machine, and the bills for furnishing the card room and repairs to the house are exceptional expenses, which will not be incurred another year.

Our financial condition on January 1, 1893, was as follows:

ASSETS.

Cash balance January 1		$299 24
Dues unpaid for 1891:		
Resident	$240 00	
Non-Resident	110 00	
		350 00
Dues unpaid for 1892:		
Resident	$ 87 50	
Non-Resident	25 00	
		112 50
Advertising bills unpaid for 1892		178 50
Advertising bills unpaid for 1891		93 50
Advertising bills unpaid for dates previous to 1891		80 00
Amount still due for Proceedings		11 00
		$1,124,74

LIABILITIES AS FAR AS KNOWN.

Chicago World's Fair Fund	$ 331 50
Overpaid dues	40 00
W. C. Kirk & Co.	18 00
M. R. Muckl, Jr. & Co., balance of loan	128 00
Wilfred Lewis, balance of loan	4 50
Salaries unpaid	145 00
Henry Veit	75 00
D. A. Partridge	114 00
Electro-Phototype Co.	12 60
W. F. Murphy's Sons	6 25
Globe Printing House	678 31
Bills payable	506 00
	$2,059 16
Deficit January 1, 1893	$934 42

The bills payable in the above statement of liabilities are notes given to the Globe Printing House in payment of their accounts.

It must not be forgotten that under the By-Laws the members two years in arrears are dropped from the rolls, and consequently dues which are not yet paid for 1891 can not be considered as good assets, as the greater part of them will probably have to be charged off to profit and loss.

Respectfully submitted:

T. CARPENTER SMITH,

Treasurer.

ANNUAL REPORT OF THE BOARD OF DIRECTORS.

For the Fiscal Year 1892.

Presented at the Annual Meeting, January 21, 1893.

To the Engineers' Club of Philadelphia:

Gentlemen:—In compliance with the requirements of the By-Laws, the Board of Directors beg to offer the following statement of the affairs of the Club for the year ending December 31, 1892.

The most important event in the history of the Club during the past year was the acquisition of a charter, which was perfected on January 9, 1892, being signed on that date by Hon. M. Russell Thayer, President Judge of Common Pleas Court No. 4. This charter enables the Club to hold real estate and personal property, and to issue notes or other evidences of indebtedness, as may be required to conduct the business of the corporation.

The Board feel that it is their duty, before retiring from office, to make some explanation to the Club for their endorsement of the amendment to the By-Laws, whereby it is proposed to increase the dues of resident members from $10 to $15 per annum. The facts of the case are that for a number of years past there has been a deficit at the close of each year, which has accumulated from year to year, until it amounted to the sum of $508.56 on January 1, 1892, as stated in the Treasurer's Report of that date.

The past year has been one in which the best efforts of the Board have been directed toward a curtailment of expenses, and in getting the Club's finances correctly adjusted. No unnecessary expenditures have been made, and there has been a net saving over previous years of more than $200, made principally in the item of salaries, and a further curtailment was made by the Board at their last meeting, which will effect an additional saving of $185 per annum.

The books of the Club show that the deficit on January 1, 1893, amounts to $934.42, an increase of $430.86 for the year. It should be remembered, however, that this does not represent a deficit in the running expenses of the Club, as it includes various bills contracted previous to 1892, for furnishing the card-room, typewriting machine, telephone and various repairs to the house, which would amount to about $500. In addition to this amount the Club received by private subscriptions, from members of the Board and others, about $200, for which the thanks of the Club are due, and this would leave a slightly greater deficit than at January 1, 1892.

The present Board have used every means in their power to decrease this indebtedness, and to this end issued, under date of June 16, 1892, a circular letter to the members, asking them to use their best endeavors to increase the membership, and setting forth the advantages of a connection with the Club. The effect of this circular may be judged when it is stated that from June 16, to January 1, the membership was increased by twenty-one Active, and one Associate Member, while in the months from January 1, to June 16, previous to issuing the circular, the membership was increased by forty-three Active, and two Associate Members.

It is the judgment of the Board, therefore, that while it would not be impossible for the Club to meet its running expenses by strict economy, with the dues at $10, and by using the initiation fees as heretofore, this total income would not leave a sufficient margin to pay off the present indebtedness, and it is their unanimous opinion that

this would not be the best policy for the Club to pursue. On the contrary, they believe that the Club can only be strengthened in influence and membership by an increase in facilities for the advancement, social and otherwise, of the interest of its members. At present, the Proceedings, although nearly self-supporting, are considerably hampered for funds, and many desirable features for the promotion of interest and activity in Club affairs, which have been contemplated by the Board, would be made available by an increase in revenue.

Another important feature of the year has been the careful revision of the By-Laws by a Committee of the Board, making them conform to the requirements of the charter, and also introducing some desirable changes. An important provision is for the election or rejection of members by a percentage of the votes cast, instead of by a fixed number of votes, as heretofore. This was adopted to prevent a repetition of the unfortunate occurrence at the last annual meeting. A large amount of work has been done by the Revision Committee in carefully considering every article of the proposed By-Laws, and it is hoped that they will meet with a favorable reception by the membership, when presented for consideration and action.

The Publication Committee has issued the regular four numbers of the Proceedings as follows :—

Volume IX, Number 1, dated January, 1892, issued February, 1892.
Volume IX, Number 2, dated April, 1892, issued April, 1892.
Volume IX, Number 3, dated July, 1892, issued July, 1892.
Volume IX, Number 4, dated October, 1892, issued October, 1892.

The Committee has made special efforts to issue the Proceedings regularly, the papers approved appearing very shortly after presentation.

Abstracts of important papers intended for discussion have been furnished when possible, and the result has been satisfactory, as is seen by the increased interest in the meetings.

The improved status of the Club's Proceedings is manifest by the large number of quotations made from it in engineering and technical journals. It is unfortunate however, that the expense of preparing the illustrations for important papers written by members of the Club has in several instances precluded their presentation for publication, and authors have, therefore, sent their contributions to other societies, and the Club has been deprived of the benefits accruing from their appearance in its journal.

The Proceedings should not be curtailed in any way, but should rather be enlarged and made self-supporting by the revenue from advertisements. The Board, therefore, avail themselves of this opportunity to urge upon the members the advantages to be gained by the use of the Proceedings as an advertising medium, and sincerely hope that individual efforts will be made to increase the list of advertisers. In this connection it will not be amiss to state that a considerable saving in postage may be made by an increase in the subscription list to a point where we can obtain pound rates. The amount saved would be about $150 per year.

The cost of issuing the Proceedings for 1892 was about $1400, the book value of the advertisements was $1016, while the receipts from advertising were $837.50 leaving a deficit between cost and receipts of $562.50, and between cost and bills rendered of $384, from which it appears that the journal failed to pay for itself by about $400. When these two accounts balance, the Board will feel that things are in their proper relation.

The Board is under obligations to Professor Spangler for seven weeks' service as Secretary of the Club, which duty he willingly performed without any compensation; and they are also under obligations to Professor Rondinella for his efficient services as Secretary, rendered largely as a matter of good-will to the Club.

The Library Committee has had all periodicals arranged and filed, and these, with new books, as received, have been added to the catalogue. An arrangement has been made by which the Club will be furnished gratuitously with "The Illustrated London News," "Engineer," "Comptes Rendus Hebdomadaires des Seances," 'Lumière Electrique," and "Harper's New Monthly Magazine," for 1893, subscriptions to which would have amounted to over $35.

The House Committee has little to report except that expenses have been closely watched with a view to keeping them as low as possible.

There have been eighteen lunches served during the year, corresponding to the number of meetings of the Club. The attendance at meetings averaged 42 (a notable increase), the largest being on April 16th, when there were 75 present.

During the year 64 Active and 3 Associate Members have been elected. We have lost 5 members by death, and the resignations of 25 Active Members have been presented and accepted. The net gain for the year is therefore 34.

The list of members at the close of the year 1892 stood as follows:

	RESIDENT.	NON-RESIDENT.	TOTAL.
Honorary	0	1	1
Active	264	177	441
Associate	12	3	15
	276	181	457

The five members whose deaths occurred during 1892 were:

Frank E. Richardson, Active Member, elected November 21, 1892, died March, 1892.

Edward Nichols, Active Member, elected December 1, 1883, died January 7, 1892.

H. W. Clarke, Active Member, elected April 7, 1883, died February 23, 1892.

Joseph Powell, Jr., Active Member, elected April 2, 1887, died December, 1892.

Joseph N. DuBarry, Active Member, elected June 18, 1881, died December 17, 1892.

The total amount received to December 31, 1892, for subscriptions in aid of the Engineering Headquarters and Engineering Congress, to be held at the World's Columbian Exposition in Chicago, was $331.50. By resolution of the Board, Mr. James Christie, Retiring President, was appointed Trustee of this fund, to hold the same, together with subsequent subscriptions, until called for by the Chicago Committee; and the amount in the Treasurer's hands was turned over to Mr. Christie on the 11th inst. It will be remembered that the original subscription of the Club to this fund was $500. The Committee in Chicago, however, advised us that they expected $1,000, and it remains for the membership to raise this amount if practicable, or, if not, to notify the Chicago Committee what they will do.

The following papers, etc., have been presented during the year:

Jan. 2.—Use of Soft Steel in Bridges, and Bridge Specifications, by Mr. F. H. Lewis.

A Large Land Slide, by Mr. Emile Low.

Jan. 16.—Annual Address, by Mr. Wilfred Lewis, Retiring President.

Annual Report of the Board of Directors.

Annual Report of the Treasurer.

Feb. 6.—East Jersey Water Company's Pipe Line, by Mr. J. J. McKee.

Feb. 20.—Limitations of Electric Power Transmission, by Mr. A. Saunders Morris.

March 5.—Cost of Producing Power in the Internal Combustion Engine, by Mr. Barton H. Coffey.

Gib and Key Compressed Cold, by Mr. W. H. Francis.

March 19.—Cost of Power in Mexico and our Western Mining Regions, by Mr. A. Falkenau.

Cost of Power in Mexico and our Western Mining Regions, by Mr. A. L. Eltonhead.

Cost of Power in Internal Combustion Engines, by Mr. Paul A. N. Winand.

Cost of Errors in Transmission of Power, by Mr. Alan N. Lukens.

April 2.—Yearly Tides, by Mr. W. S. Auchincloss.

Influence of Rainfall on Commercial Development: A Study of the Arid Region, by Mr. J. W. Redway.

Note on Engineering Civil Service, by Mr. Gratz Mordecai.

Engineering Civil Service, by Mr. Robt. A. Cummings.

April 16.—Informal Discussion of the Trolley System.

May 7.—Continued Discussion on the Trolley System.

Experimental Conduit System on Ridge Avenue, by Mr. C. H. Roney.

May 21.—An Aerial Watch Box for Railroads, by Mr. C. S. Sims, Jr.

Evaporation by Multiple Effect, by Mr. T. H. Müller.

June 4.—Location of the New Mint, by Mr. Henry G. Morris.

Shearing of Iron and Steel, by Mr. Henrik V. Loss.

Valves for High Pressure Pumps.

June 18.—Improvement of the Mississippi River, by Capt. Smith S. Leach.

Oct. 1.—The History and Development of the Injector, by Mr. Strickland L. Kneass.

Distribution of Pressure in Bearings, by Mr. Carl G. Barth.

Oct. 15.—Distribution of Pressure in Masonry Joints, by Mr. John C. Trautwine, Jr.

Investigation of the Strength of Gear Teeth, by Mr. Wilfred Lewis.

Nov. 5.—The Water Supply of Philadelphia, by Dr. Henry Leffmann.

The Water Supply of Philadelphia, by Mr. W. W. Thayer.

The Water Supply of Philadelphia, by Mr. John Birkinbine.

Nov. 19.—The Water Supply of Philadelphia, by Mr. Edwin F. Smith.

Dec. 3.—The Heating of Dwellings from a Sanitary Point of View, by Mr. Geo. T. Gwilliam.

High Speed on Railways from a Maintenance of Way and Engineering Standpoint, by Mr. Chas. S. Churchill.

Dec. 17.—Paint, as used on Engineering Constructions, by Mr. Edward Hurst Brown.

High Speed on Railways, by Mr. John C. Trautwine, Jr.

There have been 68 different contributions to the Library during the year, comprising about 100 books and documents.

With renewed hope in the future of the Club, we confidently relinquish the charge of its affairs in favor of the incoming Board.

PROCEEDINGS

OF THE

ENGINEERS' CLUB OF PHILADELPHIA.

ORGANIZED DECEMBER 17, 1877.

NOTE.—The Club, as a body, is not responsible for the statements and opinions advanced in its publications.

Vol. X.] JULY, 1893. [No. 3.

X.

THE BURNING OF PORTLAND CEMENT.*

DESCRIPTION OF THE VARIOUS SYSTEMS IN USE.

By PIERRE GIRON, Active Member of the Club.

Read April 1, 1893.

THERE are to-day five types of kilns in use for the burning of Portland cement, namely:

1. The Ordinary Dome Kiln, with intermittent burning.
2. Kiln with Dryer or Preheater, also called the Johnson Kiln.
3. The Hoffmann Kiln.
4. The Dietzch Kiln.
5. The Rotary Kiln.

*The raw material from which Portland cement is made consists essentially of silica, alumina and carbonate of lime. Oxide of iron, magnesia and sulphur in the form of sulphates, are also present in appreciable quantities. The carbonic acid gas of the raw compound disappears during the burning.

When the raw mixture is ready for the kiln, its chemical composition must be from 19 to 24 per cent. of clay (silica, alumina and iron), and from 76 to 81 per cent. of carbonate of lime. Three conditions are necessary to make a perfect compound of raw Portland cement: 1. The ingredients must be present in the right proportions. 2. All the particles should be finely reduced. 3. The whole mass of the material must be homogeneous.

It is necessary for the raw material to be perfectly dry when placed in the kiln. Only in a few cases is it possible to obtain good results with material having 5 or 6 per cent. of moisture.

1. Ordinary Dome Kiln.

Figure I shows the ordinary Dome Kiln as built in the cement factories of Europe and America. These kilns do not differ much from those used in burning lime. The height of the chamber varies from 15 to 30 feet, and the largest diameter is

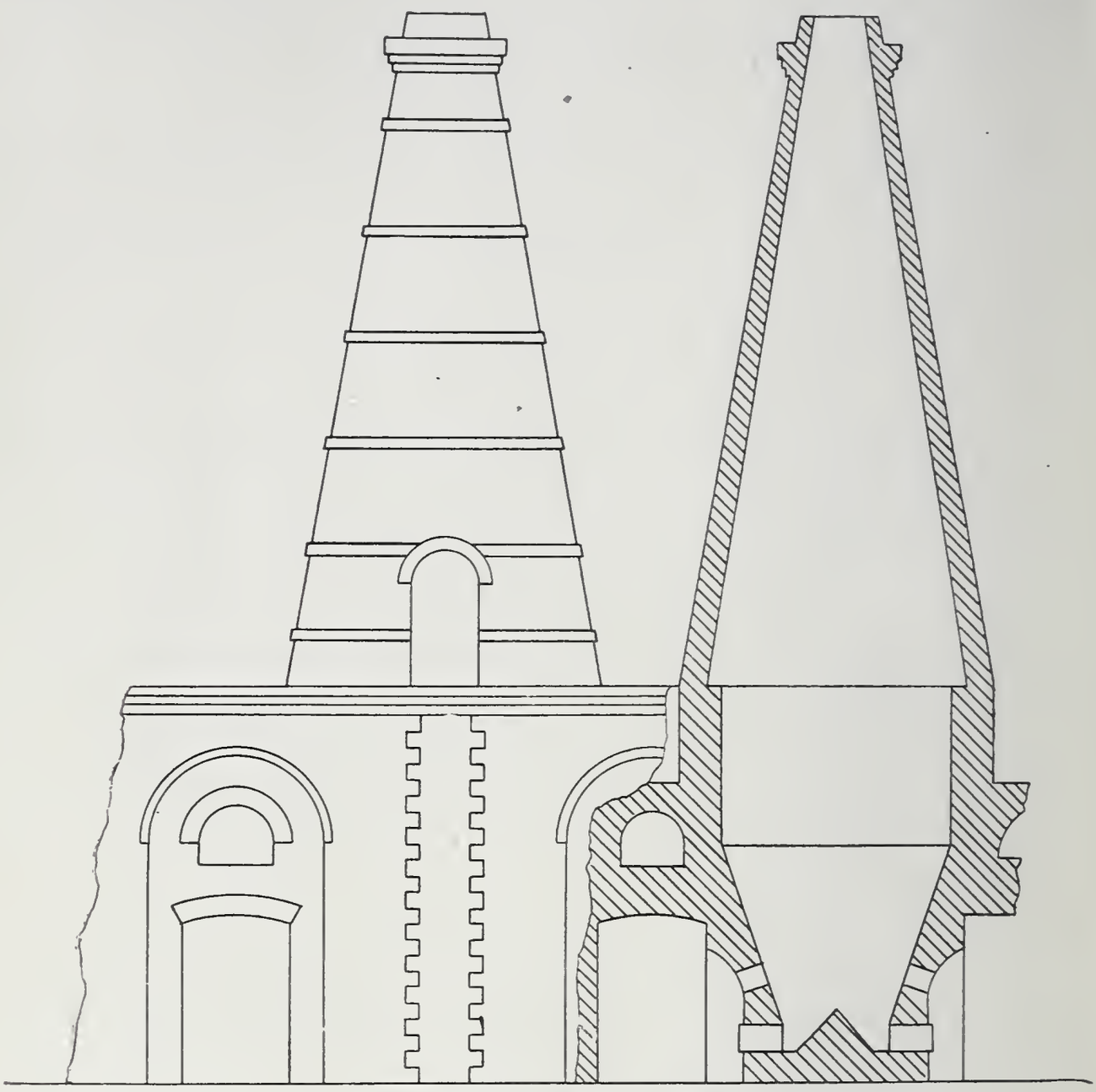


Fig. I. Ordinary Kiln.

from 9 to 15 feet. A stack, having the shape of a dome, covers the top of these kilns. The introducing of the materials and fuel is made through a door left in the stack.

The new style of Dome Kiln is represented in Figure II. The chamber is much higher, and two doors are provided for charging the kiln. These doors are both on a level with separate

floors, and as each kiln is built separate, there is plenty of room at hand for the storage of raw material and fuel. The stack is from 40 to 50 feet high, and insures at all times and in all sorts of weather an energetic and uniform draught.

The operation of a Dome Kiln is most simple. After the kiln has been filled with alternate layers of coke and raw material,

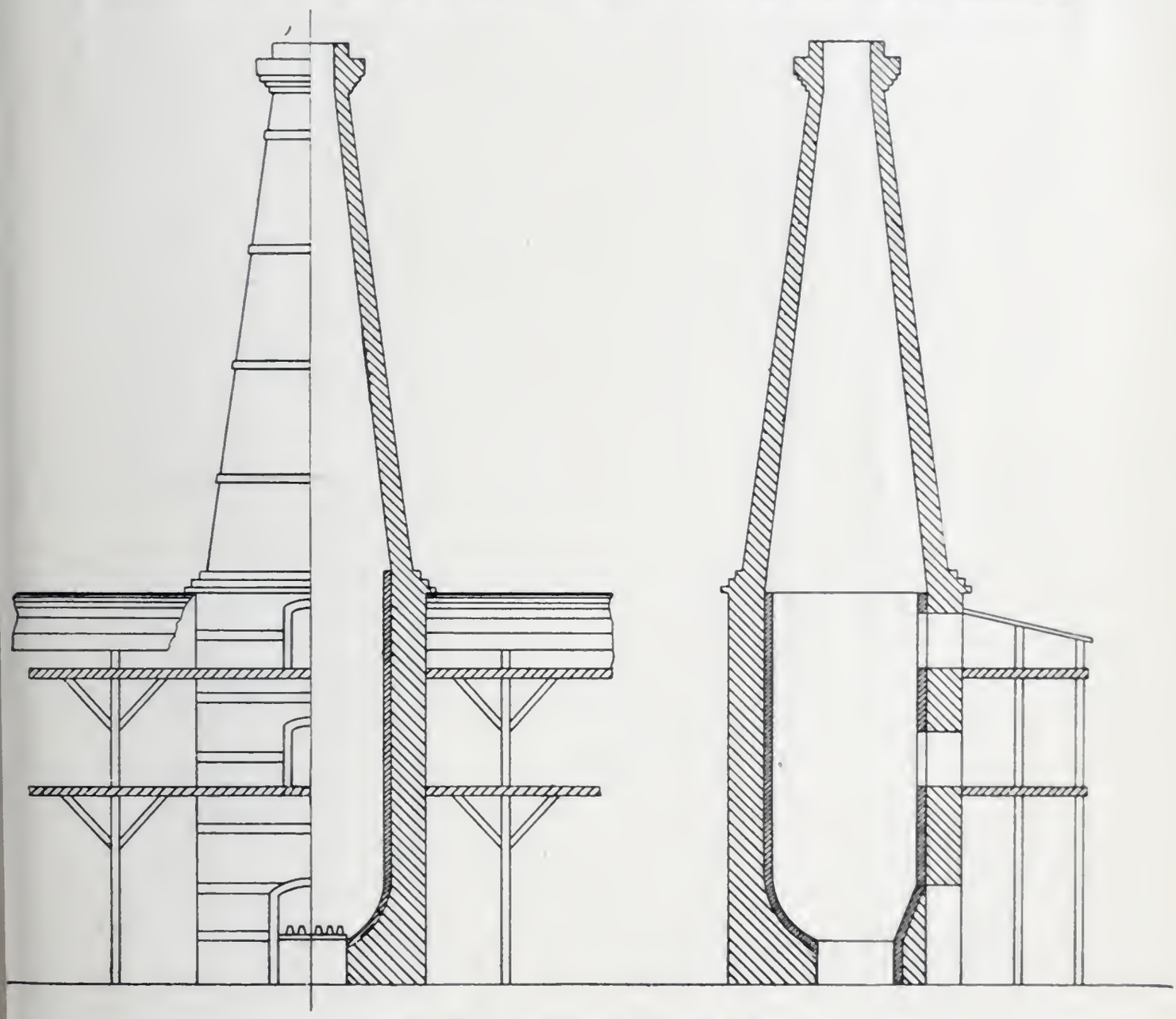


Fig. II. Improved Dome Kiln.

the doors are closed carefully and the fire is started below. The burning lasts from 5 to 6 days. The temperature gradually rises to a white heat and the fire slowly ascends to the top of the kiln. While this operation goes on, no attention is necessary. The results will only be known after the contents of the kiln are cooled off.

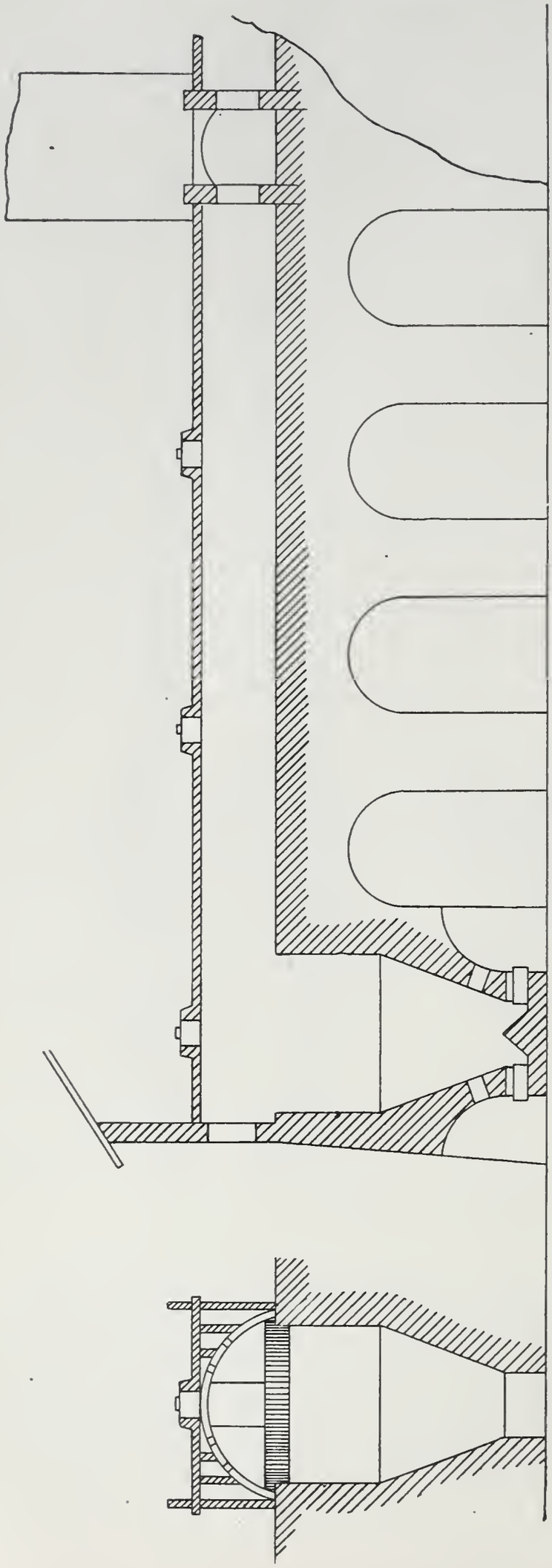


Fig. III. Drying Kiln.

All the material charged into the kiln now forms one mass of clinkers. The grate bars are removed and the clinkers are extracted from the lower part of the kiln first. The men in charge break up the clinkers fused together or which adhere to the lining. These men also make a selection of the well-burnt cement and pick out the parts that are not sufficiently calcined, to be burnt again in the next charge.

The charging, burning and drawing the charge of a kiln usually takes from 8 to 12 days, according to the capacity. The output of a kiln varies from one-half to one ton of burnt cement for every cubic yard of the space utilized in burning. The dome kiln produces on an average from 3 to 6 tons of cement per day. It takes from 450 to 600 pounds of fuel to burn a ton of cement. Coke is almost universally used, but in some cases anthracite coal can be

used also. The lining of a kiln will last about a year and needs then to be renewed in the lower part of the chamber only.

2. Drying Kiln.

A kiln of this type is shown in Figure III. The only difference between this kiln and the ordinary type is that the hot gases, instead of escaping directly through a dome, are carried into a long, horizontal channel before they reach the stack. This tunnel is generally as wide as the kiln itself, and the floor is built on a level with the upper part of the chamber. The raw materials can be brought on the floor, as they come from the wash mill in a liquid state; or, if the dry process is used, the bricks are piled upon this floor. The heat of the gases coming from the kiln below, by passing over the materials, dessicates them thoroughly, and this supply of dry materials is used for the next charge of the kiln. Fresh materials are brought in, the fire is started in the kiln, and the same operation is repeated.

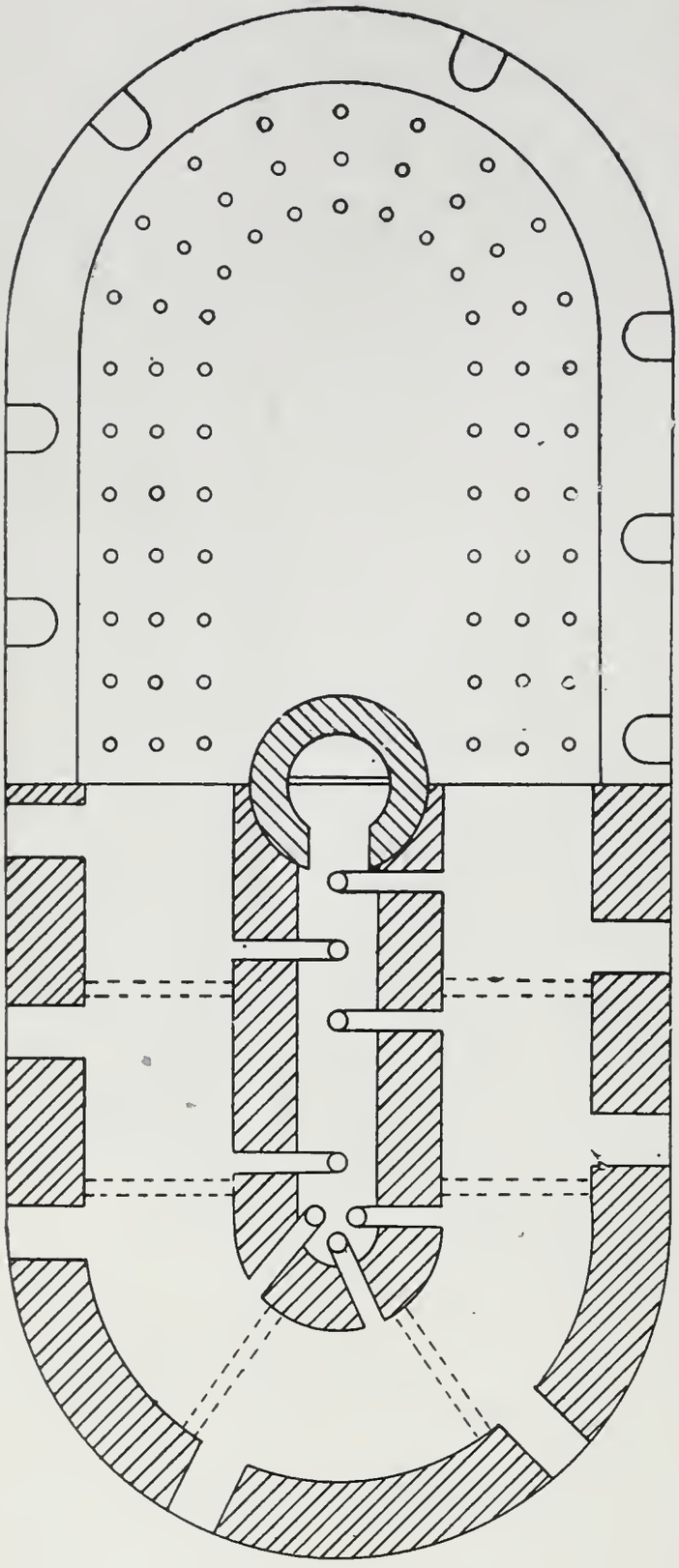
Generally one stack will serve for a group of 10 or 12 kilns. This stack is located either at the end of the drying channel, or on the side of the kilns. In the latter case the hot gases, having gone through the first channel, are made to come back to the stack through a second channel located on top of the first one. This second floor is also utilized for drying materials. The double floor channel is only applicable with the wet process.

3. Hoffmann Kiln.

This kiln has been extensively used for burning bricks; no changes are made in its general arrangements for burning Portland cement.

The Hoffmann Kiln, as shown in Figure IV, is composed of a circular gallery or two parallel galleries, with semi-circular ends. There are from 15 to 20 chambers or compartments, each communicating with the outside by a door, and connected by a special flue to the central stack.

The materials to be burnt in these kilns have to be moulded into bricks. They are piled up methodically in the kiln so as to facilitate the exit of the gases in a determined direction. When a chamber has been filled with bricks, it is closed with a sheet-



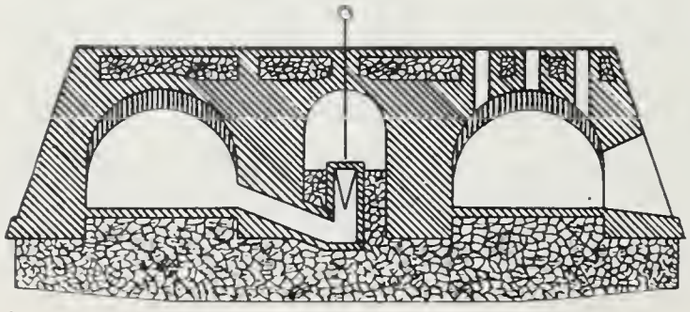


Fig. IV. Hoffmann Kiln.

iron plate, or even the whole section of the kiln is lined with thick paper. The door is also tightly shut. The preceding chamber closed before is now opened, and the new one is put in communication with the stack.

With a kiln having 18 chambers, there are 15 or 16 in use. The first five are filled with bricks; the burning is going on in the sixth; the seventh, eighth, ninth, tenth and eleventh compartments are filled with burnt cement, and the last three are empty. There is also a compartment being charged.

The fuel is introduced in the upper part of the kiln through charging holes provided for that purpose in the arch. Openings are left in the bricks, and located vertically below the charging holes, so that the fuel falls to the bottom of the chamber. The charges of coal are made at regular intervals and in determined quantity.

The burning of a compartment takes from 18 to 40 hours. Should the burning require 24 hours, for instance, during this time the last compartment full of burnt cement must be emptied, and the

first compartment ahead must be filled with bricks. Going on this way, a complete round could be made in 18 days with a kiln having 18 compartments.

The hot gases coming from the chamber undergoing burning pass through the chambers in which bricks have been piled and heat them up. When the time comes to put coal in any of these chambers, they have already been raised to a high temperature. Moreover, the air necessary for the combustion of the coal passes over burnt cement and heats itself considerably before arriving in the compartment in operation. The heat regeneration is almost complete and results in an important economy of fuel.

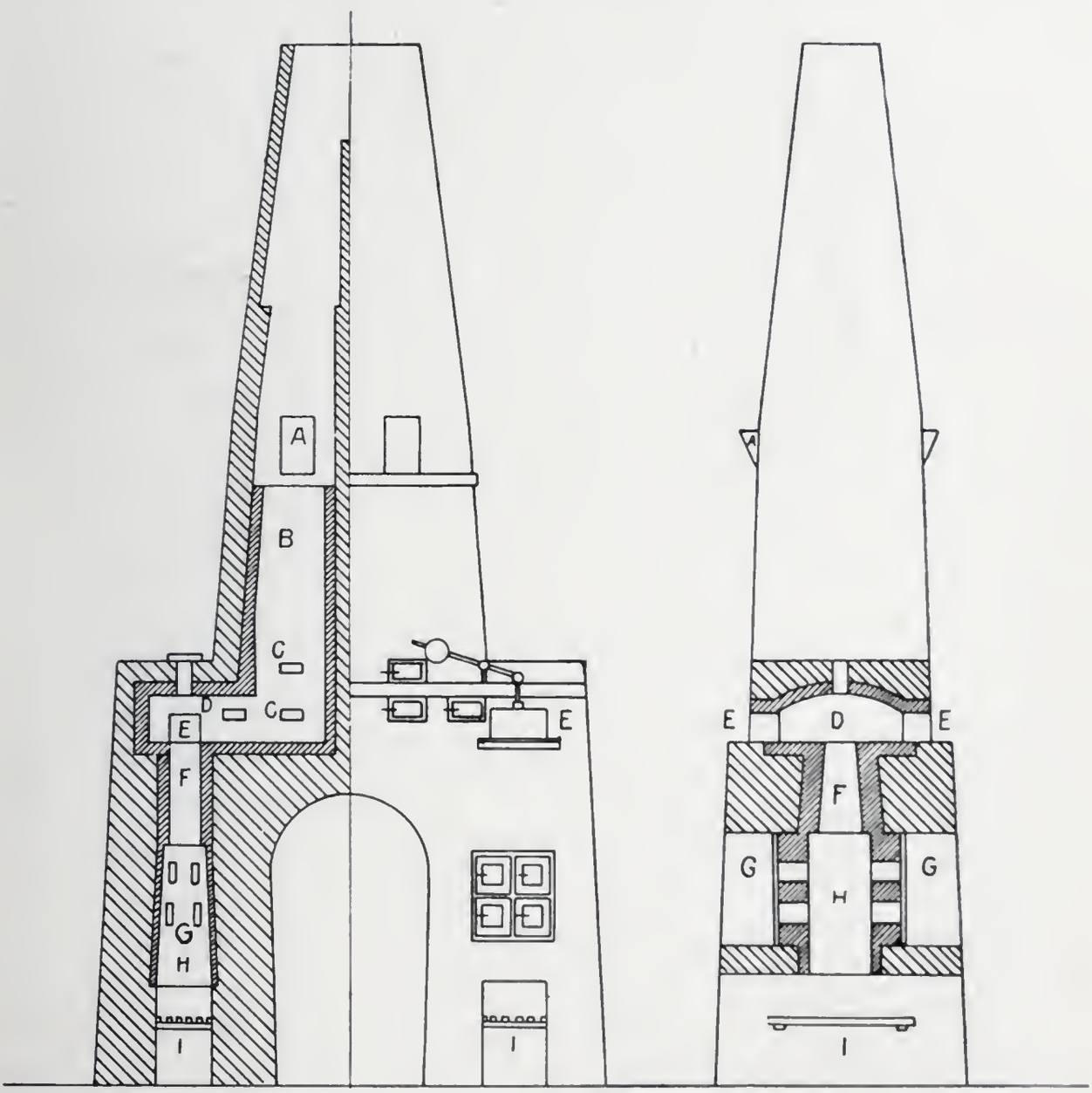


FIG. V. DIETZCH KILN.

A. Doors for loading the raw material.
B. Heater.
C. Peep holes.
D. Horizontal channel uniting the heater and the crucible.
E. Doors for the introduction of the fuel.
F. Crucible.
G. Peep holes.
H. Cooling chambers.
I. Grates.

4. Dietzch Kiln.

This form of kiln was invented in 1884 and was adopted by several factories in 1886. It is a continuous kiln, as the Hoffmann, but in the latter the fire moves while the materials remain in the same place. In the Dietzch Kiln, on the contrary, the burning is always done in the same zone. It is practically a continuously operating kiln, with this peculiarity, that the upper part is carried to some distance from the lower part and both are united by a horizontal channel.

The kiln itself, as shown in Figure V, is elliptical in shape. The part in which the burning is done is called the crucible; below it is the cooling chamber, from 12 to 15 feet high. A horizontal channel, located on the level of the upper part of the crucible, puts it in communication with the heater. The stack is rectangular and more or less high, according to the draught required. The lower part of the stack forms the heater. A convenient door is left in the stack at a height of 15 or 18 feet, to charge the dry materials which must fill the heater down to the crucible. The fuel, which should be preferably a gaseous coal, is introduced through the doors left on each side of the crucible. The hot gases pass from the crucible into the heater through the materials, the temperature in the heater becoming high enough to set free all the carbonic acid gas.

The lower part of the kiln is closed by movable grate bars, which are removed to draw a certain quantity of burnt cement at regular hours. When any cement is drawn out of the cooling chamber, all the contents of the kiln come down and an empty space is left in the crucible. This space must be filled at once with materials taken from the heater and the necessary quantity of fuel added for the burning. Charges are made generally every half hour.

The period of burning is very short. The materials remain in the heater from 12 to 24 hours; the burning in the crucible takes 1 or 2 hours and the cooling from 12 to 15 hours. The maximum temperature exists at about 4 feet below the upper part of the crucible. The air necessary for the combustion of the coal passes over the burnt cement and heats itself to a high

temperature before reaching the burning zone. The loss of heat is less in the Dietzch Kiln than in the Hoffmann, and the regeneration more complete. The economy in fuel is, therefore, greater.

It sometimes happens that the burning is pushed too far and the mass of vitrified clinkers does not come down. To overcome this difficulty, small doors are placed on each side of the kiln and at two different levels, one corresponding to the burning zone and the other about 3 feet lower. The clinkered mass can thus be attacked on several sides with strong bars and is soon disintegrated. These doors help also to observe whether the burning proceeds too fast or too slow.

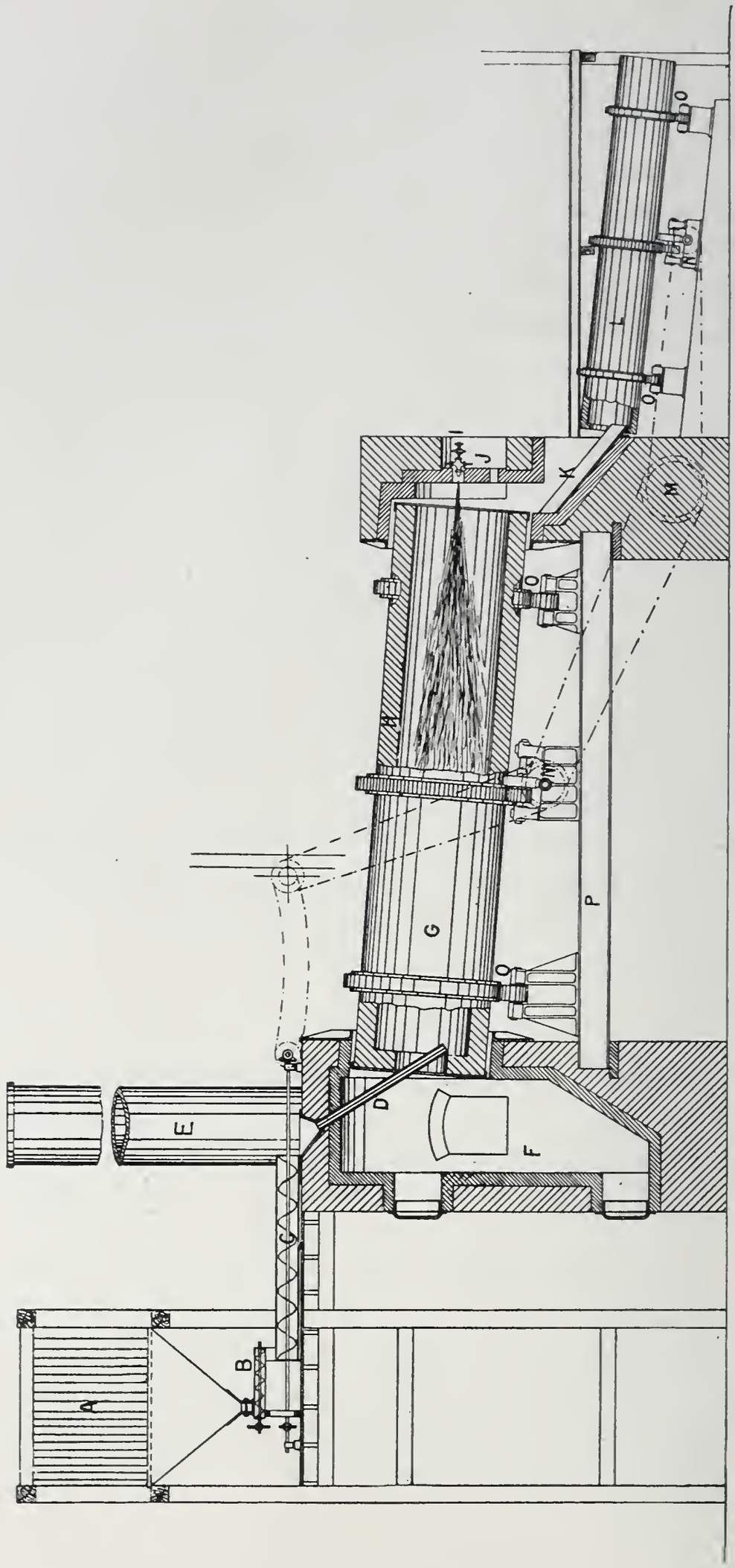
It is not possible to use for the lining of these kilns the quality of fire-bricks which would answer for ordinary kilns. These bricks would fuse after a few days, the clinkers would adhere to them and this would stop the kiln. This difficulty has been overcome by using, for the lining of the crucible, special bricks made of Portland cement. Cement clinkers are pulverized and mixed with a solution of magnesium or calcium chloride, then the paste is moulded into large-sized blocks. These bricks last very long and do not fuse as easily as ordinary fire-bricks at a high temperature.

The Dietzch Kiln can be kept in operation from four to six months without interruption. The output for twenty-four hours varies from six to ten tons of cement, according to the size of the kiln.

5. Rotary Kiln.

To operate the four cement kilns just described, the raw materials must necessarily be moulded into bricks in the case of the dry process, and it is customary, as in the wet process, to cut the paste by hand into blocks of irregular size. These bricks or blocks retain more or less of their shape after the burning, but the vitrifying heat of the kiln turns them into heavy, dense and hard clinkers.

It is evident that it would greatly simplify the manufacture of Portland cement, if the necessity of moulding the raw material into bricks or blocks could be avoided, as at the same time it would do away with the handling and drying of large



A. Bin for raw material.
B. Automatic feeder.
C. Conveyor.
D. Feed pipe (water jacket).
E. Stack lined with bricks.
F. Dust chamber.
G. Steel shell of rotary furnace.
H. Fire-brick lining.
I. Oil burner.
J. Peep hole.
K. Water-lined spout.
L. Cooling cylinder.
M. Steam engine.
N. Worm gearing.
O. Roller bearings.
P. I Beams.

FIG. VI. ROTARY KILN.

masses of material. The possibility, on scientific grounds, of burning the raw materials in a powdered condition has always been acknowledged by the best experts. It is quite an easy operation, for instance, to put a handful of raw powder in a crucible, and by heating it to the right temperature, a porous, but hard, lava-like clinker will be produced, possessing all the characteristics of Portland cement burnt in the shape of a brick. This experiment is regularly performed in laboratories as a rapid method of controlling the product of the works.

A distinguished English engineer, Mr. Frederick Ransome, resolved in 1885 to make an attempt to bring this scientific principle to commercial success. He adopted, as the most efficient means of accomplishing his purpose, the form of a rotary kiln, which had already been in successful use in various industries. Other inventors have since followed the same path, adding new details to the construction of this furnace. None of these details, however, has turned out to be an essential feature of the process.

The first trials of the Rotary Kiln for burning Portland cement were made at Grey's, in Essex. Mr. Ransome began with a cylinder 15 feet long and 18 inches wide only. No sufficiently high temperature could be reached in such a small space. The diameter of the second cylinder was increased to 24 inches, but this was still too narrow to make even a theoretical demonstration. The third cylinder was 36 inches in diameter, and some cement was made. But a fourth cylinder had to be built, 4 feet wide inside and 30 feet long, before the process could be successful. It was then proved and recorded by several experts that Portland cement could be manufactured commercially with the Rotary Kiln. Soon afterward this process was adopted in Scotland, in Wales, and in one of the cement works on the Tyne. Subsequently, however, all these attempts ended in failure, and no Rotary Kilns are in operation to-day in England.

The disappointments experienced by English manufacturers have naturally prevented the adoption of the Rotary Kiln in the cement works on the Continent. But the fact had been established that for a given quality of raw material a superior cement could be made with the Rotary Kiln, compared with the same cement burned by the ordinary process, owing to a more thorough and uniform burning, and this without consuming more fuel.

The reasons that led to the failure of the experiments carried out in England, proved to be, on examination, due principally to mechanical defects in the erection of the furnace. No kilns, built as they were then, could be kept burning more than a few days or a few hours without breaking down. It is to be regretted that the task of remedying these defects was considered hopeless.

At about the same time, similar experiments were undertaken in the United States, and for several years no progress had yet been made toward the solution of the problem.

Finally, in 1889, a cement factory was started at Coplay, Pa., and two Rotary Kilns were built. It required the most determined and vigorous efforts to overcome every difficulty, and at last success was assured. These two Rotary Kilns, the first built in this country, have been in operation ever since, and new ones have been added. Other Rotary Kilns have also been built since in different States.

A Rotary Kiln recently built in Pennsylvania is shown in Figure VI. The diameter of the steel shell is 7 feet, and the length 30 feet. The lining is 1 foot thick, reducing the inside diameter of the furnace to 5 feet. The pitch of the cylinder is equivalent to $1\frac{3}{4}$ inches per foot.

The raw materials are conveyed by machinery, in a powdered condition, into a large bin conveniently located above the furnace. This bin is provided at the bottom with an automatic feeder giving a regular supply of material. While being conveyed from the bin to the feed-pipe of the furnace, the powder is slightly moistened with hot water or steam, to prevent any of the light particles from being carried away by the draught into the dust-chamber. The cylinder is revolved slowly, and the materials gradually come down to the lower end. Going in the opposite direction, there is an intensely hot petroleum flame under pressure, which passes over the materials and escapes at the upper end of the cylinder into a stack located on the side of the dust-chamber.

The temperature inside the cylinder rises from the upper to the lower part. The materials, on entering the kiln, lose at first the water of combination, and further down the carbonic acid gas is separated and set free. The white heat of the lower end com-

pletely sinters the materials, which immediately afterward drop into a cooling cylinder of small size, revolving also like the furnace.

The amount of materials under treatment at a time inside of the furnace does not exceed three or four tons. The operation is very rapid, taking no more than half an hour from the time the raw cement is fed into the kiln until it comes out as clinkers. The operation is continuous. There is no interruption in the feed or in the output, but on account of the loss in evaporated water and carbonic acid gas, two-thirds only of the weight of materials fed in will come out as burnt cement.

The kiln and its accessories are set in motion by a vertical engine of small size, and running at a varying speed, regulated according to circumstances by the man having charge of the furnace. If, for instance, the temperature of the furnace should rise too high, the speed must be increased to accelerate the discharge of burnt cement and the inlet of cold materials. Should the temperature be too low, the motion is slackened until it has risen again. Practice soon teaches the men, under proper guidance, how they should do their work. It is not often necessary to change the speed of the furnace. The quantity of fuel and air introduced should remain unaltered.

The hot clinkers from the kiln can either be dropped on the floor and shoveled away, or they can be received at once in an iron wheelbarrow or a car. The necessity of gradual cooling does not exist, but as the increased heat of the clinkers from a large-sized furnace might be objectionable, it is better to add a small cooling cylinder, as shown in Figure VI.

Crude petroleum of the cheapest kind is exclusively used in the Rotary Kilns built in this country for burning Portland cement. Compressed air, under a pressure of about fifteen pounds, serves to atomize the liquid fuel into the furnace.

The production of a Rotary Kiln 4 feet wide inside and 30 feet long is about twenty tons for twenty-four hours, and with a kiln 5 feet wide and 30 feet long, the production amounts to about thirty tons. There is no selection to be made of the clinkers. The whole output is burnt uniformly. It is important that the raw compound treated in the Rotary Kiln should neither

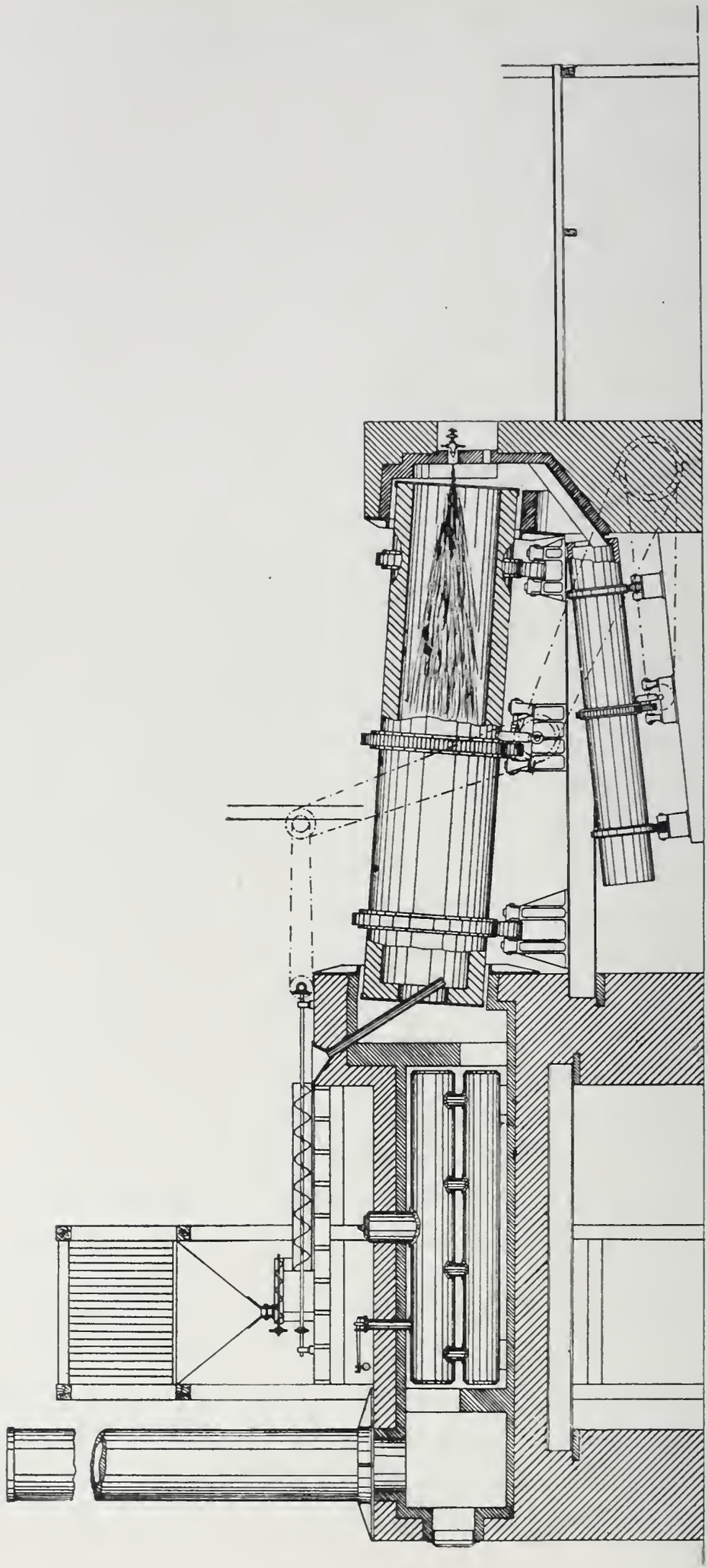


Fig. VII. Rotary Kiln with Steam Boilers.

be too refractory, as the production would fall short, nor too soft, as it is difficult then to avoid overburning. Raw materials analyzing seventy-six per cent. of carbonate of lime give the best results.

The consumption of crude oil varies from fifty to sixty gallons for a ton of burnt cement. One head burner and two assistants can operate a furnace for a shift of twelve hours. No physical effort is required on the part of the men to keep the kiln going. These furnaces run continuously, day and night, for four or six months before the lining of the lower end has to be renewed.

The heat of the burnt cement is completely regenerated by the air of combustion passing over the hot clinkers in the cooling cylinder. But the hot gases escaping from the kiln to the stack undoubtedly carry away a great deal of heat which is wasted under the present system. In Figure VII an arrangement is shown whereby the hot gases pass through a set of flue boilers to generate steam.

The process known in cement-making as "the double-kiln process" has been tried in connection with the Rotary Kiln; that is, instead of using a raw compound, the materials fed into the furnace are previously decarbonized. The absence of carbonic acid gas in the materials facilitates wonderfully the operation of the Rotary Kiln. The output of burnt cement is doubled, and the consumption of oil reduced nearly one-half, compared with the amount required for raw materials. This combination will prove very economical in places where coal is cheap and crude oil expensive.

The clinkers of the Rotary Kiln have a very different appearance from those of any other kiln. They are like irregularly rounded balls from the size of an egg to wheat. These clinkers are somewhat porous in texture. Contrary to what might be supposed, the clinkers of the new process are harder to grind to an impalpable powder than the clinkers of ordinary kilns. But on the other hand, the lumps are more easily disintegrated and no breakers are required.

An experienced cement burner can always detect any irregularities in the quality of the cement he is burning, by the appearance of the clinkers after they are cold. The presence of

many sparkling crystals on a dark-colored and heavy clinker shows an excess of lime. A deficiency of lime would be indicated by a brown-colored clinker with fused spots.

After the burnt cement is ground, the conditions regarding density, time of setting and tensile strength are exactly the same as for good cement obtained with any other form of kiln.

Conclusion.

In this study of the various methods of burning Portland cement, I have endeavored to give accurate information on each type of kilns in use. It would be unsafe to conclude in favor of any particular kiln, as so much depends on circumstances and local resources. What is best in one place may not be good in another. The selection of a burning process is, for every manufacturer of Portland cement, a matter deserving the most careful investigation.

The *Dome Kiln* has often been severely criticised as being wasteful of heat and beyond any control in its workings. But on the other hand, this kiln requires less labor than either the Hoffmann or the Dietzch Kiln. If it is true that when it works badly there is no remedy for it, it should be said also that irregularities very seldom occur. When the Dome Kiln is built on true principles, with a high stack for an energetic draught and a wide burning chamber for a large output, satisfactory results may be relied on, especially if a good quality of coke can be had at a moderate price.

The kiln with a drying chamber has been very little used outside of the London cement district. In the rest of England and on the Continent the raw materials are generally dried with special fires. Utilizing the waste heat of the kiln to dry the materials of the next charge does not necessarily save any fuel. It will be found that, while as economical in labor as the Dome Kiln, the drying kiln requires proportionately more fuel on account of the large surface of masonry which absorbs considerable heat at every operation.

The *Hoffmann Kiln* has many points in its favor, and recommends itself for factories employing the dry process. It certainly requires less fuel than the two preceding kilns, but it takes men of

long experience to run this kiln successfully; and again, the materials have to be moulded into bricks. It is a question whether the saving in fuel compensates for the increased cost of labor at the kiln and handlings of the materials.

The *Dietzch Kiln* realizes still greater saving in fuel than the Hoffmann, but the cost of labor is higher than with any other form of kiln, and the success of the operation depends absolutely on the skill, experience and attention of the burners. It is also difficult to get a very uniform burning. Although quite a number of Dietzch Kilns have been built in the last few years in many different places, it cannot be said that any serious advantages have been gained by those who have experimented with it.

The *Rotary Kiln*, arriving so rapidly at a practical success, has changed the whole aspect of the question, and it is hard to state yet what the influence of this kiln will be in the future development of the cement industry. The improvement in the quality of the burning seems to be as great as the saving in labor is remarkable. Moreover, one rotary furnace does as much work as ten ordinary kilns, costs much less to build, and occupies very little space.

It cannot be possible that this kiln should have so soon reached its limit of perfection, and the future may develop in this respect new surprises.

As the matter stands now, however, the Rotary Kiln can be successfully operated only in localities where crude oil is abundant and cheap, and it would seem that in the United States, at least, this kiln might become very extensively used. There remains the possibility of replacing crude oil by producer gas, and when this has been successfully accomplished there will be no obstacle to the adoption of this admirable form of kiln in the cement districts of Europe.

DISCUSSION.

Mr. Robert W. Lesley said: The paper just read gives a very interesting description of the various kilns in use in works of this country and Europe in the manufacture of Portland cement, and states very fairly the advantages of the several

kilns. The only point in which I feel justified in taking issue with the writer is as to his opinion in favor of the rotary kiln and the likelihood of its adoption "more generally in this country and abroad."

Cements may be broadly divided into natural cements, such as Rosendale, Union, Cumberland and Louisville cement, and artificial cement, such as the well-known Portland cement of commerce. The main distinction between the manufacture of a natural and an artificial cement is that the former consists in taking a natural cement rock, calcining it at a low temperature in an open kiln, drawing the calcined product, and grinding the same into powder; while the latter consists in taking chalk and clay, or marl and clay, or argillaceous limestone, or limestone and clay, and mixing the same together in such proportions as to produce uniform chemical analysis. This raw product is moulded into brick, blocks or other forms, making a *new rock*, containing the chemical ingredients finely ground and in close mechanical combination in the best form to be acted upon by the higher temperatures of a closed kiln, where a chemical process goes on that makes all the chemical ingredients active. This clinkered product is ground into powder and is the Portland cement of commerce. In a natural cement the low heat leaves a certain amount of the material inactive, while in the Portland cement, where the materials have been accurately proportioned and burnt, all the elements should be active.

As stated above, the principal advantage of the artificial cement is that it is an absolute uniform material, chemically proportioned and in thorough mechanical combination before being subjected to the heat of the kiln. For this reason, in considering any new form of its manufacture, it is very necessary to consider first, the quality of the product, and second, the cost of producing it. The Portland cement industry began in England, where the principal works are located on the Thames and Medway Rivers. It then spread to Germany and Belgium, and thence to the other European nations, and finally to this country. In Europe the first kilns used were of the ordinary dome-form, which were followed by a number of changes, such as the Hoffmann kilns and other kilns of the same character, designed to

avoid the patents covering the Hoffmann kilns. So far as successful manufacture is concerned, European precedents are carefully to be regarded, and in Europe the rotary kilns have not been successful. In a recent paper by Carey, presented before the English Institute of Civil Engineers, last Fall, facts are given as to the throwing out of rotary kilns in England, in the Gibbs and Arlesly Works. In Germany, Belgium, or other European countries, there is no record of the use of any rotary kilns. From my information, it would appear that this form of kiln was abandoned in England, not only on account of mechanical defects, but by reason of the poor quality of the product; and so far as the statement is concerned that when crude oil can be replaced by producer gas, "rotary kilns will become general in Europe," I may say that one of the rotary kilns thrown out in England was actually operated with producer gas. The use of rotary kilns in this country for cement-making was begun under the patent of Matte, which was based upon driving granulated cement rock, passed through crushers only, to incipient vitrifaction in rotary kilns. This process was tried on the Hudson and subsequently on the Lehigh, in this State, and proved a failure in both cases. There is a record of an attempt to manufacture cement by a rotary process in Oregon, which also proved a failure. So much for the history of rotary kilns.

Now as to the product of rotary kilns. As already stated, the product of such kilns in English works, where the cement was made by pulverizing the dried chalk and clay slurry to fine powders, and passing it through crushers, was not first-class, and the process was abandoned there. In this country the only works where cement is made by passing pulverized argillaceous limestone and limestone in a slightly moistened powder through rotary kilns, has not made cement of a reliable character. Cement produced at these works and representing the product of each one of a series of four years, was taken, made into briquettes and at the same time duplicate sets of briquettes of cement were made of various standard foreign and American Portland cements. All the briquettes were exposed to the same conditions of water and atmosphere, and in each and every case where briquettes made of the rotary cement have been kept for periods of a year

and over, they have disintegrated, while the other briquettes are sound and in good condition. For this reason I do not believe in the permanence of cement made in the rotary kilns. In order to determine the cause of the disintegration of cement so made, a series of experiments were conducted. It was found that there was a material difference in the specific gravity, in the density and in the clinkering points of the pulverized limestone and the pulverized argillaceous limestone rock, out of which the cement in question was made. These materials of these varying properties going into a rotary kiln, could not, according to my opinion, all receive the same degree of calcination, and for this reason the material produced in the shape of clinker could not be of the same uniform character as the clinker produced in the ordinary form of kiln. To verify these facts, further experiments were conducted; three samples of Standard Portland cements, English, German and American, and one sample of the rotary cylinder cement, were taken. Each sample was passed through a 10,000-mesh sieve; the residue was carefully examined. This residue from the first three cements was a greenish-black powder, highly crystallized, and of uniform color. The residue of the fourth sample was of a pepper-and-salt color. The various samples were then put under a microscope, and while the first three showed very little variation in color between the grain, the fourth was shown to consist of a number of white and black particles, the black particles evidently representing the well-burned clinker, while the white particles, when placed under microscope, were in form and shape of amorphous lumps of lime, such as can be taken out of lump lime delivered on the streets. This experiment seems conclusively to show that the lack of permanence in rotary kiln cement was due to the fact that owing to the variation in the material entering into its production, and owing to the form of the kilns and the short time taken in its calcination, that large amount of the lime-rock which clinkers at a higher temperature than the argillaceous limestone has not been thoroughly calcined, and that these small particles of lime, in the shape of caustic lime, in time cause the disintegration of work done with the manufactured cement. It is certainly either due to that fact that the trouble occurs, or to the fact that in the

manufacture of rotary kiln cement, the percentage of lime, by reason of the peculiar form of the kiln, is kept higher than in cement produced in the ordinary way, and that while all Portland cements admit of the existence of a certain small percentage of free or caustic lime, the percentage of free or caustic lime in rotary kiln cement is too high for safety, so far as permanence is concerned. The actual practical results of the use of the cement, as gathered from a number of places where it had been used, showed the same disintegration and falling away at long periods, as shown in the briquettes first referred to. On account of these and other peculiarities, the rotary kiln cement has been thrown out on a number of pieces of work, and other cement substituted for it. The most notable instance of this is on the new Reading Terminal work in this city.

Upon the second point, that of expense, there is also considerable to say. Without giving the actual cost in our works of burning a ton of cement with coke, but taking the figures of Mr. Giron's paper as correct, though they largely exceed the actual cost, it would cost $1.20 to burn a ton of cement with coke in the ordinary kiln, while by the new process the oil would cost $1.80 for the same amount, that is to say from the price I have just secured for oil from the Standard Oil Company. There is, therefore, according to the figures here given based upon the amounts given by Mr. Giron, about 60 per cent. advantage per ton of manufactured cement in favor of the old process; but as against this difference is to be set off the cost of making the raw material into brick and loading the brick into the kiln; this, when done in a large way, is quite an inexpensive item, and is possibly more than compensated by the fact that the product by the old method is porous and comparatively easy to grind, while, according to the paper read, the product by the new method is harder and more expensive to grind, because of the fact that the raw material as it goes to the kiln must be very high in lime to stand the intense heat to which it is so rapidly subjected. By reason of this fact, I am very much in doubt whether there is any saving whatever in cost by the rotary kiln process over the ordinary process now in use all over the world, and I think it has yet to be proved that it is more economical than the existing methods.

Certainly on these actual figures of cost, I do not think it has been proved, and there is another element in the rotary kiln process, which to a cement manufacturer who is depending upon the season's contracts for his season's profits, that would largely influence him against the use of the rotary kiln, and that is the great danger of having his works burn down in the midst of a busy season, and being compelled to fill his contracts which are made in the early part of the season, by buying and supplying more expensive cements. The history of the works using rotary kilns shows that within the past year two out of four works using this process have burned down, and a third works narrowly escaped a similar fate by the bursting of an oil tank car within close proximity to the plant. Certainly this element of great loss in profits, to say nothing of the added cost of insurance, is a very important one to be considered by the manufacturer who wishes permanence and success. For this reason I must adhere to my views, that in the present state of the art there is no economy in the manufacture, nor safety in the product, of rotary kiln cement.

Mr. Pierre Giron: I thank Mr. Lesley for his approval of the description I have made in my paper of the various cement kilns. I regret that my opinion on the rotary kiln and its future in this country is not acceptable to him. The objections raised by Mr. Lesley, although not suggested to him by any personal experience with the kiln in question, should be answered for the satisfaction of those who are interested in the advancement of the cement industry. I am in a good position to do this, as my efforts during the last five years have been specially devoted to the development of the rotary kiln process in the United States.

The failure of the rotary kiln in Europe up to the present time has been fully related in my paper, and I have also alluded to the failure of the early experiments made here, and upon which Mr. Lesley insists so much. Considering the value of the product of rotary kilns now running in this country, Mr. Lesley relates experiments made by himself on samples of such cement as were found in the market, I suppose, and he says that all the briquettes he made at different periods were found, with-

out exception, to have disintegrated. Furthermore, Mr. Lesley intimates that the results of the cement in practical use showed in a number of places the same disintegration at long periods. How can I reconcile this sweeping condemnation of a product with the fact that the manufacturers of this product are constantly increasing their output? The old cement kiln has been in use in this country for the last twenty years, and the rotary kiln has been made a success only about three years ago. Yet, the capacity of the works running under the rotary kiln process is already about as large as the capacity of the works running under the old process.

In the case of the failure of the samples of rotary kiln cement which came into Mr. Lesley's hands, it may be that the cement was really bad, or the samples were perhaps injudiciously selected. At any rate, we often hear also of experimental and practical failures with cements burnt in the old form of kiln. When cement of any kind shows lack of stability, it does not follow that the burning is the cause of it; a faulty preparation of raw materials is generally the source of such troubles, and errors made in this part of the manufacture are followed by exactly the same consequences, whatever form of kiln is used. To pretend that the rotary kiln necessitates the production of an overlimed cement, is merely a flight of the imagination.

But if there is such a number of places where the practical results of the use of rotary kiln cement have shown its lack of stability, it would be well to know the actual value of such general information. The only instance given, that of the new Reading Terminal in Philadelphia, shows, on the contrary, that nearly all the cement used in this vast structure was cement burnt under the new process, and it is at least singular that such a fact as this, which the manufacturers of rotary kiln cement consider as the best and most intelligent endorsement they have of the value of their product, should be taken by Mr. Lesley as an argument against the rotary kiln. When he says that time alone and long periods of use can demonstrate the safety of unknown or untried cements, Mr. Lesley revives an old objection, the unfairness of which he knows very well, as it has been frequently used against himself. To say this is to ignore the fact

that the testing of cement is fortunately to-day a positive science, and that simple methods exist to ascertain at once the stability of all kinds of cement.

The real point at issue is, whether good and reliable Portland cement can, under favorable circumstances, be produced by the rotary kiln. Mr. Lesley does not deny squarely that it can be done. He is satisfied to take the case of an establishment where the raw materials consist of two kinds of rock of different chemical composition. He attempts to show that the same degree of calcination cannot be applied in a rotary kiln to a mixture of these two kinds of rock. In his experiments to ascertain the difference in specific gravity, density and clinkering point between these materials, Mr. Lesley arrives at conclusions entirely different from my own. I can assure him that the difference in specific gravity, etc., between these two raw materials is hardly measurable, and after a thorough mixture and grinding, the resulting product is perfectly homogeneous. The residue, on a fine sieve, of cement made of these materials shows also a very different aspect from the one described by Mr. Lesley, and without using a microscope, which would be superfluous in the matter, I will say that the presence of white particles of lime, under such circumstances, is an impossibility. Free or caustic lime might be present to a dangerous extent in cement, but a microscopic examination is not the way to detect it, and still less to measure it.

Nothing proves better the value of rotary kiln cement than the fact that it has been from the start, and is getting daily more generally used in the best class of engineering works. The evident superiority of rotary kiln cement, as shown by the tests of experts and the results of actual work, has early overcome the natural prejudice of consumers, and as to the interested opposition of competitors using the old process, it has been on the whole much less troublesome than might have been expected.

In regard to the cost of burning a ton of cement with coke in the old kiln, and with oil in the rotary kiln, I have avoided in my paper naming any prices, as these evidently vary with localities. But in figuring the cost of fuel oil, Mr. Lesley places the price at three cents a gallon, while the actual price is from 2 to $2\frac{1}{2}$ cents only. The statement of Mr. Thomas Whittaker, who spoke

from actual experience in the matter, corroborates mine; on the other hand, the handling of oil at the works, to which no expense is attached, cannot be compared with the handling of coke.

In a general way, it is safe to say that the cost of crude oil and the cost of coke in burning a ton of Portland cement is about equal for the same grade of cement. The economy of the rotary kiln is in the enormous saving of labor. No one will believe that the cost of making the raw material into bricks, drying the bricks, loading and unloading the kilns, is an inexpensive item. The extra cost of grinding the rotary kiln cement is sufficiently compensated by the economy in not having to crush the clinkers. They are easily disintegrated in a pot cracker.

The great danger of having the works burn down where rotary kilns are used is illustrated by Mr. Lesley stating that within the past year two of these works have burned down. One of the mills here referred to was lost by fire while it was not running, and this accident was not traced to the use of oil. In many industries to-day fuel oil is extensively used with perfect safety, and insurance companies charge no extra rates where their requirements for the safe use of oil are complied with.

XI.

NOTES ON ENGINEERING IN MEXICO.

By John Birkinbine, Active Member of the Club.

Read May 6, 1893.

Several members of the Engineers' Club were connected professionally with the location or construction corps which laid out and built some of the railroads in Mexico, and pilgrimages to our Sister Republic are now made by many of our citizens, hence I shall not offer such data as might have been appropriate eleven years ago, after making a journey of nearly 2,000 miles in "diligencias," and on horseback, through a portion of the Mexican Republic, in advance of the "ferro carrils," which now traverse much of the ground then covered by the more tedious, but more interesting method.

In a late trip I rode between 500 and 600 miles, in comfortable sleeping-cars, over territory which little more than a decade ago was accessible by slow, exhausting wagon-travel only, requiring camps on the plain, or stops at ranches far from other habitations. The story I then told to wondering, if not skeptical, natives, of travel at the rate of ten to fifteen leguas (twenty-five to forty miles) per hour, in the United States, has become a familiar sight in daily railway trains; and the new Conquest of Mexico by the Engineer is an accepted fact.

One who now journeys by railroad views Mexico modified by foreign influences. In 1882 it was my privilege to see a considerable portion of the country as it had been for centuries, and yet to-day, the tenacity with which older methods or appliances are adhered to is evident by glances from the windows of moving cars, which in an hour cover as great distances as could formerly be traversed in a day by a team without relays.

The tourist notes, side by side, a modern steam dredge doing its work in competition with nearly nude peons, who carry on their backs "tenates" filled with earth, removed by pick and shovel. In other instances, modern steam pumps are raising

water for railroad requirements, while, near by, women and children use the balanced sweep and bucket, or, in the absence of mules or oxen, push around the bars of a windlass, or "malacate," thus giving motion to a series of leather buckets or earthen jars attached to ropes, raising water in this way from wells for domestic or irrigating purposes.

In view of the scarcity of water in Mexico, the regularity with which winds blow over much of the country, from a certain direction, for a great part of each year, and the acknowledged age of the windmill, it seems strange that this medium for utilizing energy, which can be so readily harnessed to work, should be slightly used; for, with the exception of a few in the mining regions, where foreign influences predominate, or in some of the larger cities, I saw no windmills at work.

A journey made before the country awakened from its long sleep permits me to properly appreciate the work of engineers in locating and constructing the railways. The traveler now rides comfortably over long tangents, whose extremities are lost in the horizon; he enjoys changing views as the train winds around sharp curves in a development to obviate steep gradients; he is attracted (unless a suburban resident on the main line of the Pennsylvania Railroad) by the novelty of one or more tank cars (similar to our oil cars), each holding 5,000 gallons, or more, of water, carried next to the engine, to convey the train over long stretches of waterless and treeless prairie, with only a few scattered ranches to indicate a scant habitation; but he has little appreciation of the difficulties which the locating or constructing engineer corps had to contend with, in addition to the personal risk from hostile Indians at times. A camp made at the end of a day's work, to which water and provisions must be conveyed long distances, with the nearest shade leagues away, is an experience contrasting with that of a locating party in Pennsylvania, resting for a midday lunch under cooling shade, beside refreshing waters, or foraging on neighboring farmers, where three kinds of meat and six kinds of pie tickle the appetite of the young engineer from the city.

In my first journey made with mule teams, it was often necessary to carry drinking water in canteens, and the problem of a

water supply has been a serious one, not only for the locating and constructing parties, but subsequently for the operation of some of the railroads of Mexico. Much of the water throughout Northern Mexico is so alkaline as to give trouble in boilers, and the annual rainfall of 20 inches or less is unevenly distributed. Thus at Ciudad Porfiro Diaz, on the Rio Grande, 20.125 inches of rain fell in 1892, of which all but 2.19 inches were precipitated in the six months from May 1st to November 1st. In August 8.66 inches, and in October 4.18 inches of rain fell.

When traveling in Mexico, in 1882, the country had less than 300 miles of railway. According to the last message of President Diaz, there are now in operation, in the Republic, 6,831 miles of rail and tram roads (exclusive of street railways), and although access to detailed profiles for all of the lines was not practicable within the time at command, an examination of a majority of the elevations gave an approximate basis for the following table:

Of the tracks of railroads in the Republic of Mexico about

15	per	cent.	only	are	less	than	1,000	feet	above	sea	level.
10	"	"	are	between	1,000	and	2,000	"	"	"	"
6	"	"	"	"	2,000	"	3,000	"	"	"	"
10	"	"	"	"	3,000	"	4,000	"	"	"	"
13	"	"	"	"	4,000	"	5,000	"	"	"	"
15	"	"	"	"	5,000	"	6,000	"	"	"	"
15	"	"	"	"	6,000	"	7,000	"	"	"	"
13	"	"	"	"	7,000	"	8,000	"	"	"	"
3	"	"	"	"	8,000	"	10,000	"	"	"	"

To summarize this table, three-fourths of the entire railroad mileage in Mexico is at elevations greater than are reached by any of our Pennsylvania railroads, and about one-half of the Mexican tracks are below, and one-half above a level of 5,000 feet; of the higher portions some 200 miles are laid from 8,000 to slightly over 10,000 feet above sea level.

The following statistics of railway construction in Mexico for 1890 and 1892 have lately appeared:

Description.	Kilometers to Dec. 1890.	Kilometers to Dec. 1892.	Kilometers increase 1891–1892.
Government Railways, built under concession,	9,162.72	10,557.99	
Suburban Roads, . .		185.29	
		10,743.28	1,580.56
Private Lines, . . .	202.38	301.25	56.37
Light Railways, . . .	42.50		
Street Railways, . . .	314.28	354.10	39.82
	9,721.88	11,398.63	1,676.75
Miles, . . .	6,041.18	7,083.11	1,041.93

Of the 9,162.72 kilometers (5,693.71 miles) constructed up to December, 1890, 5,290.70 kilometers (3,287.64 miles) were of standard gauge of 4′ 8½″ and of these 4,880.32 kilometers (3,032.63 miles) were worked by steam power, the balance being worked either wholly or partially by animal power. The remaining 3,872.02 kilometers (2,406.07 miles) were all narrow gauge and all operated by steam.

(Note.—All tramways in Mexico worked by animal power are broad gauge, to admit of traction by a pair of mules driven abreast.)

The topographical features of Mexico consist, generally, of comparatively narrow coast plateaus, skirted by abrupt ridges, causing heavy grades for railroads leading from the Gulf or from the Pacific Ocean toward the interior plateaus. The branch of the Atchison, Topeka and Santa Fé standard gauge railroad known as the Sonora Railroad, which is entirely within the State of Sonora, enters Mexico at Nogales, at an elevation of 3,875 feet, and shortly after it reaches its summit at Encino, 350 feet higher; from this point, with few exceptions, the road has a descending grade, the maximum being 2 per cent., reaching the Gulf of of California at Guaymas, 260 miles from Nogales. The Mexican Central Railroad (standard gauge), built principally on the Central plateau, crosses the Rio Grande at an elevation of 3,700 feet from El Paso, Texas, and its 2,000 miles of line are between this elevation and 8,000 feet, except some 200 miles, principally

on the Tampico Division, reaching to the Gulf of Mexico. The Central Railroad engineers started to construct the road with easy gradients and curves, and on this account it has decided advantages in freight transportation. Of the 750 miles from El Paso to Fresnillo, only about fifteen miles exceed a grade of 0.5 per cent., the maximum being 1.5 per cent. To cross the summit at Zacatecas, 8,045 feet above sea level, required considerable development, but between this point and the city of Mexico, 440 miles, there is only about fifty miles with grades greater than 0.5 per cent., but not exceeding 1.5 per cent.

The Tampico Division of the Central Railroad, extending from the Gulf at Tampico to Aguas Calientes, 415 miles, crosses the National Railroad at San Luis Potosi, and reaches a maximum elevation of 7,250 feet, while the Guadalajara branch, of 161 miles, is entirely between 5,000 and 6,000 feet above sea level. In ascending from the Terra Caliente to the plateau, the Tampico Division passes through great cañons by grades of 3 and 4 per cent., with sharp curves and numerous short tunnels, the engineering work rivalling that of the Mexican Railroad.

The Monterey and Mexican Gulf Railroad, 387 miles long, has a less troublesome line. Starting at Tampico, on the Gulf of Mexico, it runs in a general northwestern direction, crossing the National Railroad at Monterey, and has its terminus at Trevino, where it intersects the International, reaching its highest elevation, 2,870 feet, at that town.

The International Railroad (standard gauge), crosses the Rio Grande, from Eagle Pass, Texas, at 720 feet above tide, the lowest point found on its 600 miles of railway, and has a nearly continuous ascent to Durango, the present terminus of the road, 180 miles from the Pacific Ocean, which is at 6,200 feet elevation, The road is favored by having on its line deposits of bituminous coal, which supply its engines and also furnish some of the fuel for the Mexican Central Railroad. The maximum grade on this line is 1 per cent.

The National Railroad (three-foot gauge) enters Mexico at Neuvo Laredo, crossing the Rio Grande at an elevation of 530 feet, and the main line in 168 miles reaches Monterey, which is considerably above the elevation of Altoona; from here a steep

rise is made to Saltillo, and from Saltillo (with the exception of the Matamoras branch) all of the balance of the company's lines in Mexico is above 5,000 feet elevation, the maximum being 10,020 feet, within twenty-five miles of the capital, the steep ascent over the summit being made by Baldwin Compound locomotives, hauling passenger trains of five and six day coaches and sleeping cars with apparent ease.

These roads are all laid throughout with wooden sleepers.

The Mexican (standard gauge) and the Inter-Oceanic (three-foot gauge) railroads both connect the Gulf at Vera Cruz with the city of Mexico, and have but a small portion of their tracks on the lower levels; the former passes an elevation of 8,225 feet, the latter, one of 8,967 feet, in reaching the city of Mexico from the Gulf. The engineering features of the Mexican Railroad, on the construction of which £8,000,000 have been expended upon 263 miles, have been liberally described and published, and attention need only be called to the Fairlie double bogie engines used on eighty-two-pound rails, on the steeper grades, and the growing employment of metal sleepers. The Inter-Oceanic Railroad, by reason of a longer but more lightly built line (342 miles as against 263 miles), has better grades than the Mexican Railroad, but passes over a higher summit. On this road the use of metal sleepers is also meeting with favor, and the same may be said of the Southern Railroad (three-foot gauge), now built from Puebla southeast to Oaxaca, and the Pachuca Extension of the Mexican Railroad (standard gauge), both laid with iron sleepers.

The Hidalgo Railroad (three-foot gauge), the branches of the Inter-Oceanic and National Railroads, the Tehauntepec Railroad, the several short lines on the Pacific coast, could all be noted, but an attempt at detail is not intended, nor does a journey over but half of the total railway mileage entitle one to describe the entire system.

The following suggestions concerning the use of metal sleepers are offered, as of interest to the Club.

The Mexican Railroad has now some 150 miles of track, including the Pachuca branch, laid with steel ties which weigh 124 pounds each, or 126 pounds with the two key bolts. These

ties are 8 feet 3 inches long, rolled so as to have a longitudinal web, and have clips for holding the rails formed by cutting slots out near either end of the sleeper, and bending up the steel. The first metal ties, of crude design, were placed on this road fourteen years ago.

On the Inter-Oceanic Railroad some fifty miles had been laid with "pot" sleepers; an English design, consisting of two cast-iron dishes, oval in form, which were inverted in the ballast and connected together by wrought-iron bars, the rails being keyed to the pots; about one-fourth of these have been replaced by steel sleepers, and further replacement is made as rapidly as finances permit. The rolled steel sleepers now substituted for pot sleepers are 6 feet long (for a three-foot gauge road), weigh 90 pounds each, and have, near the ends, square bolt holes, but no clips; these nest nicely for shipping, and cost $1.00 gold per sleeper, delivered at Vera Cruz.

Wooden sleepers, 8 feet by 6 inches by 6 inches, cost, in the vicinity of Puebla, Mexico, 63 cents for pine and 95 cents for oak; therefore, at the present exchange, the pine sleepers cost, in gold, 42 cents and the oak ties 64 cents each; as railroad supplies pay no duty, the expense for steel ties is not greatly in excess of wood.

On the Southern Railroad (three-foot gauge) steel ties, 8 feet long, weighing 110 pounds, are used.

The testimony of engineers, of managers and of contractors, all favor the metal tie for its permanence, its stiffness, yet resilience, the facilities for ballasting, etc., and the experience of smooth riding satisfied me with the advantage of a permanent feature of railroad construction little used, so far, in the United States. In fact, the entire journey in Mexico was free from the roughness too often characteristic of new roads, or those built through sparsely settled portions of our country, even where the construction could be cheaply carried on. The long stretches of Mexican prairie or of table-lands offer excellent facilities for rapid railway construction; but where an obstacle was met, either as an "arroyo" or a cross ridge, the spanning of one, or the abruptness of ascent and descent of the other, demanded engineering talent in locating the roadway.

The alternate wet and dry seasons of each year further complicate the work of an engineer, for the bed of a stream dry for eight months, becomes a great torrent, subject to frequent sudden rises, during the remaining four months of the year. There are, however, comparatively few notable bridges, tunnels, deep cuts or high embankments in Mexico, but numerous instances of development of road-beds, cuts in the sides of steep mountains or of deep cañons, supplemented by few important bridges and by tunnels of moderate length, vary the monotony of long tangents. The most notable cut is the Tajo Nochistongo, an old canal, along the slopes of which the tracks of the Mexican Central Railroad are laid.

This cut, however, was not made for the railroad, but is a part of what was intended to be the drainage system for the city of Mexico, and is now used to carry water from a river and lake north of the Capital. The original plan suggested in 1607, and which was carried out later, was the construction of a tunnel four miles long, and twelve miles of canal. The tunnel, it is reported, was 10 feet wide and 14 feet high, and the tunnel and canal were finished in less than a year. The tunnel was not lined, and constantly caved in; afterwards it was partially lined, but in 1629 there was a great inundation, when the opening proved insufficient, and about 1650 it was decided to convert the tunnel into an open cut. Mr. Richard E. Chism, a native of Philadelphia, but a resident of Mexico, and editor of *El Minero Mexicano*, the only engineering periodical in the Republic, says, in an interesting article upon the drainage of the valley of Mexico, that "this Nochistongo canal is a work that has no equal, even in our day of railroads. It was finished in 1789, about 150 years after being commenced, at a cost of $5,550,000, without counting labor of Indians, of whom tens of thousands were employed at a time, and compelled to work for nothing. The canal, as it exists to-day, is three miles long; for 2,624 feet its width at the top varies from 278 to 360 feet, its depth from 147 to 196 feet; for 11,483 feet its depth is from 98 to 164 feet." The excavation for the canal was made principally by means of laborers carrying the material in sacks on their backs. Enrico Martinez, the engineer who designed the tunnel and drainage system, was

complimented by having his monument placed in the "Zocola," a plaza in the city of Mexico, and there it remains an exhibition of attention which engineers seldom receive.

At present extensive operations are being carried on for draining the valley in which Mexico is located (it being entirely surrounded by hills) through a system constructed at a level much lower than the Tajo Nochistongo. This improvement consists of a canal 30 miles long, which is being constructed by contract, and a tunnel 5.6 miles long, which is driven at the expense of the Government, giving a mean discharge of 620 cubic feet per second. The canal is in two sections, one of 20 kilometers and the other of 28 kilometers, the former being about one-third the capacity of the latter section. The total length, therefore, will be 48 kilometers, or nearly 30 miles, and the total amount of excavation was estimated at 12,000,000 cubic meters (nearly 16,000,000 cubic yards). The tunnel is semi-ovoid in form, with a useful section of 7.79 square meters (83.5 square feet), and a total section of 12 square meters (129 square feet). The grade of the whole canal is 2-100 of 1 per cent., the total fall in the canal being 31.5 feet, or 1 in 5,000. The slope in the tunnel is 1-10 of 1 per cent., or 1 in 1,000. The maximum depth of cutting on the canal is 91 feet at the tunnel mouth. Where the excavation is deep, the first 10 or 12 feet are removed by peons, working in gangs of three, two filling the bags for the third to carry on his back and dump, 100 feet away from the excavation. These peons work principally by tasks, and handle from five cubic meters of sand at the top, to two cubic meters of "tepatate," or volcanic tufa, at the bottom, of this upper level per day, receiving therefor 50 centavos, which at present rate of exchange equals 33 cents. After the first benching by peons, the steam dredges are put to work, and of these there are five, lifting the material, by chain buckets, from 40 to 70 feet, into hoppers. Water equal to twice the volume of earth is then discharged into the hopper, and chutes convey the material to either side the canal, about 80 feet from the dredge. These dredges are operated by compressed bituminous coal blocks, brought from Cardiff, Wales, costing 19s. 9d. per ton delivered at Vera Cruz; the railroad haul of $9.00 Mexican being added to this makes

the coal practically cost by the time it reaches the dredges $16.50, equivalent to $11.00 United States currency per ton. The maximum work per dredge has reached 2,000 cubic meters, or say 2,600 cubic yards per day, the average being about 800 cubic meters. Up to April 1, 1893, about two-thirds of the 12,000,000 cubic meters had been handled, and three of the five years allowed by the contract had passed.

The figures of the cost of labor and of coal will show that in considering the problems in Mexico which are presented to an engineer, he must approach them from a different standpoint than in the United States, and economies must be determined from different bases. As a rule, in Mexico, fuel is expensive and labor cheap; labor-saving devices cannot, therefore, show to great advantage when peons work from sun to sun for a stipend of from 18 to 75 centavos, and where coal commands from $10 to $25 per ton. A failure to appreciate these conditions has resulted in serious losses, and the expensive machinery equipments, which either lie idle or are converted into scrap, indicate how often the economic condition of Mexico has been misunderstood.

The Two Republics, an English newspaper published in the city of Mexico, says, in an editorial column: "It is officially announced that the average daily wage in this country is 27 cents. This is probably at least 10 cents more than it was 20 years ago. In 10 years we believe it will average 50 cents at least."

Labor in Mexico is abundant, of satisfactory quality, and quickly adapts itself to changed conditions, while the rates of wages are low as compared with those prevailing in Great Britain or the United States. Out of a population of 11,600,000 in the Republic, probably 8,000,000 consist of those who earn laborers' wages, and their families.

In railroad work, throughout the Republic, the wage rate is generally 2 reals and a media, or 31 centavos, in the high latitudes, or 3 reals, or 37 centavos, in the hot country. The highest rate of wages which came under my notice was in the machine-shops and foundries in the cities of Mexico and Puebla, where 6 reals, or 75 centavos, per day were paid.

Skilled labor receives better compensation. Mechanics earn,

say from one dollar and a half to four and even five dollars, Mexican, per day. Visits were made to foundries and machine-shops, and other industries, to investigate the labor problem, and to note the readiness with which the natives adapt themselves to various trades and to different kinds of work. As a rule most of the employés were Mexicans, with foreign foremen, and a few foreign specialists, but in one machine-shop visited, the Mexican vise-hands and some operating the larger tools received higher wages than any foreigners employed. In the foundries the entire force excepting the foremen are Mexican, and in one foundry making a high grade of castings the foreman was also a native.

The testimony of the managers or owners of these works is that the native element quickly adapts itself to new employments, and while individuals may not work as rapidly, in many cases, as Europeans or Americans, the character of the work they turn out is in no way slighted.

Mules still drag stones around in arrastras, or plod in the patio, in what seems to be an extravagant and wasteful process, not because better methods are undiscovered, but because existing conditions do not favor their use. Thus, at Zacetecas I learned that with coal at $15 per metric ton it was found to be more economical to raise water from a mine 400 feet deep, by means of a "malacate," or horse-whim, to which was attached by ropes two "botas" made of ox hide, each holding from one-half to one ton of water, than to pump by steam.

When great quantities are to be handled the economies of steam can show to better advantage, and in the prominent silver mining districts of Pachuca, Zacetecas, Catorce, etc., the ancient crude mining appliances are found side by side with modern machinery and equipment, some of the appliances being of great size, and costing enormous sums of money.

An interesting example of this is the mining camp at Catorce, a settlement in northeast Mexico, 10,000 feet above sea level, accessible only by horse-trail, where some of the mines are wrought in truly primitive style, and others equipped with electric appliances equaled or excelled by but few mines in the United States.

The abundance and cheapness of labor makes the people of the country, in many cases, veritable beasts of burden, but the manner and apparent ease with which they handle and carry long distances, up steep slopes, loads which in our own country would encourage a laborer to call for assistance to move a few yards, indicates that the peons of Mexico are physically able to perform a large share of work.

One who passing through our Southern States notes the serpentine furrows in which crops are planted, and then travels in Mexico and in the great pulque district sees the mathematical precision with which the maguey plants are planted, will become impressed favorably with the ability of the Mexican to carry out work entrusted to him with exactness. Sighting over rows of maguey plants, their tops will be found to form a straight line for a mile, and sometimes more, and the plants are in a majority of cases so placed that whether one sees them in a line at right angles to the road, or parallel with it, or at an angle, the tops of the plants practically form straight lines.

The geological survey of Mexico indicates carbonaceous formations within convenient distances of the Capital, and some lignite is obtained locally, but the railroads (except the International and in part the Central Railroads) rely upon wood, or upon coal brought from the United States or Great Britain, after expending large sums of money seeking for a local supply of mineral fuel.

Bituminous coal is mined in the State of Coahuila, 900 miles from the city of Mexico, and liberally employed, and coke is also produced from this coal, but the quality of the coke made up to the present time is not sufficiently good to encourage an attempt to transport large quantities long distances, even if it could be obtained more cheaply.

Both bituminous and anthracite coals are reported as existing in the State of Oaxaca, specimens of these fuels in the cabinet of the Mining School showing it to be of apparently good quality; but no practical means of communication exist between the important cities and these coal deposits, nor is it probable that they will become immediately available, in fact little is known as to their actual extent and true character.

The following prices for coal and coke in the cities of Mexico and Puebla are presented to show the rates ruling for fuel:

PRICES OF COAL IN MEXICO PER METRIC TON.

	City of Mexico.	Puebla.
English bituminous coal,	$17 00	
" " " blocks,	16 25	
Alabama bituminous coal,	21 00	
Coahuila coal,		$26 00
Welsh coke,	27 00	
Indian Territory coke,	22 00	
Coahuila coke,		27 00

The liberal use of wood in Mexico continuing for centuries has depleted the available timber and fuel supply, the remaining wooded areas of the country being chiefly in a few mountain ranges, and in a territory but sparsely populated. Later requirements, such as sills and fuel for railroads, have advanced the cost and taken the best timber accessible in many locations.

A feature of particular interest was a visit made to the National Engineering College, a well-equipped palatial building in the city of Mexico, having twenty-seven professors, a large number of students, library, museum, meteorological, physical and chemical laboratories, and other necessary appointments. Its departments embrace Civil, Topographical, Hydraulic, Geodetic and Electric Engineering, besides Mining and Metallurgy, the students in the latter finishing their course by spending two years prior to graduation at the practical mining school at Pachuca, at present the most important mining city in Mexico. There is also a State mining school at Guanajuata.

This National Engineering College is supported by the Government, and education throughout Mexico is now made compulsory; it was my privilege to see public schools in session, even in remote portions of the country.

While visiting the National Engineering College two masses of meteoric iron were being placed in position at the doorway. This is called the Meteorite de Chupaderos, and was found in 1581, near Jiminez, in the State of Chihuahua, 900 miles from the city of Mexico. In falling it broke in two pieces, which

have been lately transported to the Capital and set up at the college. The one piece measures 2.15 meters long by 1.1 meter wide, .5 meter in thickness, and weighs 9,290 kilogrammes. The second piece measures 2.5 meters long by 2 meters wide, by .4 meter thick, and weighs 15,600 kilogrammes, a total for the two pieces of 24,800 kilogrammes, or nearly 25 tons. The density of these masses is 7.8. In the museum there are models of other large masses of meteoric iron, but none of such immense proportions as that just described.

During a former visit, while passing through the State of Chihuahua, I saw and obtained a photograph of a large meteorite, upon which four men are standing. This is the Meteorite de San Gregorio, found about the year 1600, near what is now the village of Allende, in Chihuahua. It is conical in form, about 1.1 meter in diameter at the base, with a height of 1 meter, and weighs 11,560 kilogrammes, 11 tons. Its density is 7.74. It is also to be brought to Mexico. Senor Antonio del Castillo, director of the Mexican Geological Survey, has written an interesting monograph upon Mexican meteorites, describing quite a number in addition to the above, among which may be mentioned one mass of meteoric iron found in 1792, near Zacetecas, weighing 1,000 kilogrammes; two found in 1780, in the State of San Luis Potosi, weighing 576 and 578 kilogrammes respectively; one found in 1864 in the State of Oaxaca, weighing 421 kilogrammes, and one found in the State of Chihuahua, weighing 3,130 kilogrammes. About a score of large masses of meteoric iron have been discovered, in addition to numerous small pieces, and many meteoric stones—no less than fifteen Mexican States contributing these interesting productions. Full-sized models of the meteorites of Chupaderos, San Gregorio and others are shown in the Mining Building of the Columbian Exposition.

Mexico has evidently given attention to Hydraulic Engineering, and numerous aqueducts show that large expenditures have been made to bring water considerable distances into the cities. Many of these aqueducts, such as those immediately about the city of Mexico, are abandoned and in ruins; and in the State of Hidalgo I saw one, of large size, claimed to have never been in use, because the aqueduct as constructed was higher than the source of supply. One of the most impressive of the remaining

aqueducts is that which was built, a century and a half ago, to supply the city of Queretaro, which traces its history back for 450 years, to the time of the Aztecs, and which had been a city for 250 years before William Penn came up the Delaware river. This aqueduct, which brings water five miles, has seventy-four impressive arches, through one of the highest of which the tracks of the Mexican Central Railroad pass. The engineer of this aqueduct is honored with a statue in the plaza Queretaro. The Mexican National Railroad also passes through an arch of an aqueduct at Jajalapa.

The Mexican aqueducts were not arranged to deliver water under any considerable pressure; they either supplied a series of gutters passing through the town, or else discharged the water, under light pressure, at fountains, from whence it was carried in vessels on the heads or backs of women, on the backs of burros, or on wheelbarrows or carts especially arranged for the purpose. There seems to be a considerable opening in the near future for Hydraulic Engineering in the Republic of Mexico. Very few of the more important towns have water brought and distributed under pressure, and as advancements are made the number of those which provide for a water supply will probably increase.

The city of Mexico has lately contracted for additional water supply, and an English contractor is now completing a gravity system under high pressure for the city of Pachuca. In this connection some prevailing prices may be quoted with advantage.

The prices paid per pound for wrought and cast iron in Mexico, Puebla, and other important cities of the Republic, are influenced by the depreciated Mexican currency; for, expressed in equivalents of United States or British coin, at present rates of exchange they would show the following:

	Mexican Centavos.	United States Cents.	British Pence.
Bar iron, ordinary sizes, . .	8 to 12	5 to 8	$2\frac{1}{2}$ to 4
Ordinary casting, . . .	10 to 12	$6\frac{1}{2}$ to 8	$3\frac{1}{4}$ to 4
Nails, ...	12 to 14	8 to $9\frac{1}{2}$	4 to $4\frac{3}{4}$

The alternation of wet and dry seasons, and the long continuation of one or the other, particularly the predominance of dry weather, as well as the necessity for irrigation to make much of the table land of Mexico productive, also offer possibilities for

the construction, on a liberal scale, of impounding reservoirs in the mountains, to store water for irrigation or other uses during the protracted dry spells. A scheme based upon that proposed by Major J. W. Powell, Director of our Geological Survey, would appear to offer as good, if not better, advantages for Mexico than for the United States, and it is probable that reservoirs, if constructed of large areas, would not only encourage a greater growth of vegetation, but (particularly if the present announced policy of the Government favoring forestal protection is carried out) also in time partially change the unfavorable climatic conditions which exist. With more rain, or with the rain more evenly distributed throughout the year, or held in store for a time, the altitude of the main plateaus of Mexico would make it one of the most desirable portions of the world for locating, particularly for those interested in agriculture.

The following table, exhibiting the areas and population of the various States in the Republic of Mexico, prepared from the official publications of the *Ministerio de Fomento*, gives data to the close of the year 1890. The areas are given in square kilometers, the measure adopted by the Government publication. As one square mile is equal to 2.59 square kilometers, the area in square miles is readily calculated.

TABLE OF AREAS AND POPULATION.

CENTRAL STATES.

STATES.	AREA. Square kilometers.	POPULATION.
Federal District,	1,200	443,181
Aguascalientes,	7,644	121,926
Durango,	98,470	265,931
Guanajuato,	29,458	1,007,116
Hidalgo,	23,101	494,212
Mexico,	23,957	778,969
Morelos,	7,184	151,540
Puebla,	31,616	839,468
Queretaro,	9,215	213,525
San Luis Potosi,	65,586	546,447
Tlaxcala,	4,132	147,988
Zacatecas,	64,138	526,966
	365,701	5,537,269

NORTHERN STATES.

Chihuahua,	227,468		298,073	
Coahuila,	164,690		177,797	
Nuevo Leon,	61,118		270,958	
Sonora,	199,224		154,532	
		652,500		901,360

GULF STATES.

Campeche,	46,855		91,180	
Tabasco,	26,094		118,028	
Tamaulipas,	83,234		188,497	
Vera Cruz,	75,651		633,369	
Yucatan,	91,201		275,506	
		323,035		1,306,580

PACIFIC STATES.

Baja Californio (Territory),	151,109		34,668	
Colima,	5,887		69,547	
Chiapas,	70,524		299,941	
Guerrero,	64,756		382,887	
Jalisco,	82,503		1,159,341	
Michoacan,	59,261		834,923	
Oaxaca,	91,664		739,419	
Sinaloa,	87,231		223,684	
Tepic (Territory),	29,211		125,294	
		642,146		3,869,704
Islands,		3,681		unknown
Total,		1,987,063		11,614,913

The total area of Mexico is therefore 767,206 square miles, with an average population of 15.14 per square mile. The central States, as recognized in official publications, have an area of but 18 per cent. of the total of the Republic of Mexico, while the population of these States represents nearly 50 per cent. of the inhabitants of the Republic, and the number of inhabitants to a square mile in the central States is 39.

The territory in the immediate vicinity of the extinct volcano, Popocatepetl, the summit of whose comb reaches an elevation of nearly 18,000 feet, and its neighbor, Iztaccuihuatl,

whose snow-cap is some 2,000 feet lower, is largely devoted to the cultivation of a species of the maguey plant, specially adapted for the production of the national beverage, "pulque." The area utilized for the growth of this plant extends close to the peak of Orizaba, which is somewhat higher than Popocatepetl.

The consumption of pulque in Mexico City alone, with a population of 330,000, amounts to 750 barrels, equivalent to 300,000 pounds, daily, that is, every adult drinks nearly one pound of pulque per day. The cultivation of the pulque plant is principally in the States of Hidalgo, Mexico, Puebla and Tlaxcala, where it is estimated that the value of the pulque haciendas exceeds $10,000,000. It is only in the States named, and in certain districts of those only, that the pulque plant seems to grow to advantage; in fact, the pulque plant, or maguey, thrives in certain favored districts of Mexico as it does nowhere else.

Weights, measures and money in Mexico are used in an incongruous way. Although the metric system of weights and measures was adopted by the Government thirty years ago, most commodities are transferred from buyer or seller by the inexact, old Spanish basis, in which pulgadas, pies and leguas represent inches, feet and leagues. Cuartillo, almude, fanega and carga are used instead of quarts, pecks, bushels, etc., and grano, onza, libra, arroba and quintal correspond closely with our grain, ounce, pound, quarter and hundred-weight.

The following are some United States and metric equivalents, given by Mr. R. E. Chism, of Mexican weights, measures and money:

MONEY.

	English.	United States.
1 Mexican peso or dollar = 100 centavos,	33d.	66 cents.
1 " real = 12½ centavos, . .	4⅛d.	8¼ "
1 " centavo, ...	⅓d.	⅔ "

LINEAR MEASURE.

	Metric.	English.
1 legua = 5,000 varas, . .	4.19 kilos.	2.604375 miles.
1 vara = 3 pies, . . .	0.838 meters.	2.749578 feet.
1 pie = 12 pulgadas, . .	0.27933 "	0.916526 "
1 pulgada = 12 lineas, . .	0.02328 "	0.916526 inch.

Square Measure.

	Metric.	English.
1 square legua, . . .	1755.61 hectares.	4339.4 acres.
1 square vara, . . .	0.702244 sq. meter.	7.559 sq.feet.
1 square pie, ...	0.078027 "	0.84 "

Cubic Measure.

1 cubic vara, . . .	0.588480 cu. meter.	0.769734 cu. yds.
1 cubic pie, . . .	0.021795 "	0.769484 cu. feet.

Commercial Weights.

	Kilogrammes.	Avoirdupois.
1 quintal = 4 arrobas, . .	46.024634	101.444 pounds.
1 arroba = 25 libras, . .	11.506159	25.361 "
1 libra = 16 onzas, . .	0.460246	1.01444 "
1 onza = 16 adarmes, . .	0.028765	1.0148 ounces.
1 carga = 12 arrobas, . .	138.073902	304.332 pounds.

XII.

A VISIT TO THE WORKS OF THE WELLMAN IRON AND STEEL COMPANY AT THURLOW, PA.

By H. C. Lüders, Member of the Club.

Through the courtesy of Mr. S. T. Wellman, President of the Wellman Iron and Steel Company, a number of the members of the Engineers' Club of Philadelphia enjoyed the privilege and pleasure of a visit to the extensive works of that company at Thurlow, Pa.

The party, consisting of some twenty-five members, under the leadership of Mr. John Birkenbine, President of the Club, and accompanied by Past-Presidents Christie, Lewis and Spangler, left the Broad Street Station at Philadelphia, on the afternoon of June 17, 1893, and after a short run over the Philadelphia, Wilmington and Baltimore Railroad arrived at Thurlow. Proceeding on foot, the visitors were cordially received at the office of the company by Mr. Wellman, who conducted them through the works.

The property, which is situated on the Delaware River, covers a large area, and is completely equipped with wharf and track facilities for convenient handling of raw and finished materials, and for distribution to all parts of the country.

Passing through the yard, the visitors were conducted into the open hearth building, where several furnaces of large capacity are located. The casting pits are sunken into the floor at one side of the row of furnaces, whilst on the other side an elevated iron floor, ten or twelve feet high, is provided with a narrow-gauge track for the cars bearing the materials, flanked by another track, upon which an ingenious charging machine sweeps the whole line of furnaces.

The materials are placed in iron boxes or troughs of uniform size, carried on cars on the narrow-gauge tracks, and each provided with a socket in the end, into which the arm of the charging machine is made to enter and clutch the box so firmly that it can be lifted from the car and moved in any desired direction.

The device for charging is of novel design, and seems almost endowed with human intelligence; it is driven entirely by electricity from an overhead trolley wire through a combination of motors. A man, comfortably seated, handles the switches, and causes the machine to move along the rails to any desired point. The projecting arm is then dropped, and engaging in the socket in the end of one of the loaded boxes previously described, lifts it from the car, thrusts it into the furnace, turns it upside down by a revolving motion to empty the material, and then withdraws the box and returns it in proper position to its place on the car. This device makes it possible to charge turnings and light scrap with the same facility as heavy material.

After viewing the interior of the furnaces through colored glasses, to screen the eyes from the intense glare of the fires, the party witnessed the process of pouring a heat.

The iron moulds are arranged in a circle around a central vertical pouring gate, provided with lateral runners, one to the bottom of each ingot mould; in front of each furnace are two platforms revolving in a horizontal plane, one of which carries the ladle into which the metal is tapped, while the other serves as a platform for the men required to open the tap hole and direct the operation of pouring.

The ladle having been filled, it is swung out directly over the pouring gate in the midst of the group of moulds; an outlet in the bottom is then opened, and the molten steel pours through the vertical gate and lateral branches into all the moulds at one and the same time.

A few minutes suffice to complete the operation, the steel rising in the moulds until all are filled. After cooling, the gates are broken off and the ingots removed from the moulds.

Having witnessed the operation of casting, the next process shown was that of rolling.

The ingots are reheated in gas furnaces, a long row of which are located under the same roof as the rolls. A track traverses the length of this building, bearing a traveling steam motor which carries a device similar in some respects to the charging machine previously described. In this case the arm carries a pair of tongs or nippers on the end, which, being actuated by

electricity, is made to reach into the furnace, grasp and withdraw the heated ingot, and hold it suspended in its jaws whilst the motor carries it to the table in front of the rolls, where it is dropped.

The tables in front and behind the rolls are supported on horizontal bearings, and arranged to tilt up and down, to bring the ends opposite either the lower or upper roll, and are provided with a number of shafts, bearing a multitude of wheels upon the vertical edges of which the ingot is placed.

The rolls are three-high and arranged so that the middle roll rises and falls to allow the ingot to pass back and forth, first under and then over it.

The train being in motion, the table rollers are caused to revolve, and the ingot is carried to the rolls, through which it passes between the middle and bottom roll to be caught on the table at the back of the train. The motion of the table rolls is then reversed, and at the same time the table tilts up, the middle roll drops, and the ingot returns and passes between the middle and top roll, to be caught again on the front table, which then drops to its original position. This operation is repeated until the ingot is reduced to a plate of the desired thickness and width. A few men are at hand to direct the ingot, and produce, by cornering or turning, the proper dimensions.

When the plate is completed it is shot off the rear table to the floor by simply allowing the table rollers to continue their motion in place of reversing.

After cooling, the plates are trimmed to size, ready for shipment.

At the time of this visit the company was executing orders for ship plates, $1\frac{9}{16}$ inch thick, from mild steel.

A most interesting and, to many, novel device examined was the magnetic crane for handling and loading plates.

A traveling crane carries an electro-magnet of such power that when placed upon the flat side of plates ten feet wide and fifteen feet long, and the current applied, they are lifted as if by magic, and remain adhering without any visible means of support while being moved in any desired direction. The current being switched off, the spell is broken and the plates drop on the car or pile as the case may be.

The extensive application of electricity in these works was a revelation to some of the visitors, and the complete facilities for handling raw materials seem well calculated to reduce cost to a minimum. Coal is dumped from gondola cars into pits and carried thence, by endless chain driven by electricity, to the top of a huge pile, under which a tunnel is provided; cars are run into this tunnel and filled, from above by gravity, for distribution throughout the works.

After examining the Bessemer plant (not in operation), and the steam, electric and hydraulic appliances, and witnessing the mode of testing samples in the laboratory, the party, which had been joined by Mr. S. H. Chauvenet, Vice-President of the Company, and several members of the Club, who arrived on later trains, assembled in the rear of the office and were photographed by the Club Photographer.

Returning to the city, a number of the members partook of a subscription dinner at the Continental Hotel, at which President Birkenbine presided, about twenty-five covers being laid.

At the meeting of the Club in the evening, a resolution of thanks to Mr. Wellman for his courtesy was unanimously adopted.

Thus ended what it is hoped may prove but the first of a series of similar profitable and enjoyable excursions by the Engineers' Club of Philadelphia.

NOTES AND COMMUNICATIONS.

VERTICAL PRESSURES FOR HIGH MASONRY WALLS.

In answer to the question as to the rules prevailing among architects and builder for vertical pressures that can be safely borne by high masonry walls, it was informally stated by Mr. W. C. Furber that the rules which prevail among architects and builders for proportioning of high masonry walls are, to a large extent, empirical ones. These rules, under ordinary conditions, give safe results. All large cities, however, have building regulations which prescribe minimum thickness for various heights, and which are supposed to have been derived from observation and practice. There is, nevertheless, a marked difference in what each city considers sufficient. An empirical rule, which gives safe results under most circumstances, is to start at the uppermost story with walls 1½ bricks in thickness and increase each story ½ a brick descending. These figures will do for warehouses and heavy buildings, but are too large for the ordinary light buildings.

Perhaps the most approved and generally accepted formula for calculating the safe thickness for high masonry walls is that given by Louis de Coppet Berg, which is a modification of Rankine's formula for long columns; and while too long for complete insertion here, can be found in Berg's *Safe Building*.

LOAD FOR BALL BEARINGS.

In opening the discussion, Mr. Wilfred Lewis explained that the question was intended to cover roller bearings as well as ball bearings, and that in view of the large and increasing demand for these bearings, it was remarkable how little de inite information could be obtained concerning them.

Some time ago he wrote to a prominent manufacturer of ball bearings for such data as could be given in regard to the carrying capacity of hardened steel balls between plates of the same material, and in reply he was informed that almost nothing was positively known. Some crude experiments have been made upon ⅜-inch balls, which showed them to have an ultimate strength of 2,000 pounds, and a safe working limit of 400 pounds; but for car journals, in which the motion was continuous and rapid, 200 pounds per ball was recommended as preferable. Whether a ¾-inch ball would carry twice as much or four times as much as a ⅜-inch ball, could not be stated, but the impression seemed to be that, over a given extent of surface, more load could be carried on small balls than on large ones. The effect of hardening was believed to increase tenfold the carrying capacity of a ball bearing.

In regard to roller bearings, but one formula is known to be in common use. This makes the load carried by any given roll proportional to the square root of its diameter, and the general adoption of this formula may be credited to the authority of the late C. Shaler Smith, while the investigation upon which it is based is said to be due to Prof. Grashof.

A number of questions were asked by members present concerning the durability of ball bearings and their frictional resistance as compared with plain bearings, to which Mr. Lewis replied.

Mr. H. V. Loss gave a summary of Prof. Grashof's investigation of the subject, with blackboard illustrations.

Mr. Carl G. Barth reviewed the ground covered by Mr. Loss, showing how the same results might be obtained from the assumption of Grashof by an original and somewhat different treatment of the problem.

In doing this he also showed that Smith's rule, although sanctioned by Grashof, was derived by a misleading reduction from the latter's formulas, which, when properly interpreted, left no room to doubt that the capacity of rolls of different sizes was directly proportional to their respective diameters, while the capacity of balls was proportional to the diameter squared. This indicated that for any given extent of surface the capacity of a roller or ball bearing was independent of the size of the rolls or balls used.

Mr. Loss contended that apparently this conclusion was not borne out by facts, and instanced a case in which large rollers had been unable to carry a given load and small rollers had been substituted with success.

Mr. J. Sellers Bancroft thought experimental investigation was needed more than theoretical conclusions, and suggested a method by which he proposed to solve the problem in a practical way.

IMMEDIATE PUBLICATION OF PAPERS.

Mr. Wilfred Lewis stated that the Publication Committee had recently received a request for the immediate publication of a paper, and as it could not appear in the Proceedings until after July 1st, they desired the opinion of the Club as to what course was best to pursue in such cases. While a paper published in this way was not so fresh when it appeared in the Proceedings, there was more opportunity for its general discussion and for its republication in technical journals.

Dr. Leffmann argued that, while its first appearance in our Proceedings would give them a greater journalistic value and increase their attractiveness as an advertising medium, on the other hand, if the Proceedings were intended merely as a record, the immediate publication of papers would be advisable, and would probably better satisfy their authors. Whether the Club could afford to do away with the income from the Proceedings which resulted on account of the originality and newness of the material in them, was a question that should be carefully considered.

Mr. Gill stated that the Publication Committee believed the Proceedings could be issued monthly, if there was sufficient material, at the same expense as for the present quarterly issue, since a larger number of advertisements could probably be secured.

On motion, the matter was referred to the Publication Committee, to report early in the Fall, giving all the facts, and a recommendation as to the best plan for the future.

IMPROVING THE PRESENT STATUS OF THE ENGINEERING PROFESSION.

The Secretary read, at the request of Mr. Horace W. Sellers, a paper on that subject by Mr. H. F. J. Porter, which was presented at the last November meeting of the American Society of Mechanical Engineers.

He especially called attention to the desirability of making the professional degrees really indicate to the general public the capability of the engineer who used them, by having them conferred by a Board of Regents, embodied with power to confer titles for merit. It should be capable of judging what a man should know in order to bear a title, should endeavor to bring to unity all methods among the schools as to an engineering education, and should confer titles after a term of practice and after passing an examination, upon those entitled to them, thereby practically licensing the recipient to practice. It would not be absolutely necessary to attend a technical school to obtain a title, as a self-taught genius, proving himself capable, would be awarded one. A more natural division of the different branches of engineering was suggested, with a recommendation that the province and duties of the engineer in each division should be well defined, and that the practice of a man should be confined to those divisions in which he is competent and licensed to practice. It was thought that this matter might profitably be taken up at the Engineering Congress in Chicago, next August, and that the General Committee might act as the Board of Regents above mentioned.

Mr. Birkinbine stated that the tone of the general discussion which this subject had received in the technical journals tended to bar out from the use and benefits of a degree those who had not received one as the result of a college education, and that such a plan would work a great injustice to the self-made engineer, whom engineering societies and the world at large had in the past seen fit to honor.

Mr. G. Bacon Price called attention to one point of difference between the other learned professions and that of the engineer not generally considered; namely, that the community had not yet come to realize its need for the intelligent engineer, as it did for the doctor and the lawyer, for example, and that there was not at present a demand for their services to in anywise meet the numbers turned out by our technical schools. Whether a man has a degree or not, if his services are necessary and efficient his reputation will rise accordingly. Most of our young engineers, however, find it necessary to associate themselves with corporations or in partnerships in order to obtain a sufficient practice.

SOME DATA IN REFERENCE TO MODERN OFFICE BUILDINGS.

Mr. C. H. Roney opened a verbal discussion on the above subject by calling attention to the rapid changes which had taken place in the construction of buildings of this class within comparatively a few years. Formerly they were built like dwellings, and of not more than five or six stories, but now the introduction of elevators has been followed by an increase in height to an average of twice the above number of stories. All parts of the construction are made as fire-proof as possible, wood being used only where nothing else can be substituted for it. Methods of supporting the floors, and bracing to withstand wind pressure, were described and illustrated by blue prints of typical buildings in Chicago and Philadelphia. In some cases the columns of successive stories support one another, and in others are made practically continuous. A model of the Phœnix column, showing the latter method, was presented as an illustration. Other details of construction were described by Mr. Roney, and in conclusion a series of photographs were projected by the lantern, giving typical examples of modern office buildings in various stages of completion.

Mr. Howard Constable inquired of Mr. Roney whether he had formed any opinion as to what was the practical deviation from the vertical allowable in the erection of the main columns of high buildings and frame-work of elevator shaft.

Mr. Constable's opinion, in a special case was, that $1\frac{1}{2}$ inches in 200 feet was too much in an elevator shaft to be passed as first-class work, and not within the limit of what should be allowed for general practice. He called attention to the fact that this was a point upon which engineers would have to post themselves, as it bears an important relation to disputes between the structural contractors, the stairbuilders, and the elevator people. These disputes arise from the pressure that is brought to bear to complete these buildings in a very short period; therefore, the rapid getting in of stairs and elevators becomes very important, although very little of the work is got out until measurements from the building can be taken,—the manufacturers of these parts generally finding it very unsafe to work from drawings, and feeling no certainty as to what the deviation on the part of the other mechanics will be.

He also called attention to the fact that, as yet, very little attention is given by the Architect and Structural Engineer, to providing for the various pipe-systems necessary in all high buildings. He thought they ought to be planned for as carefully as many other parts, and showed how the putting in of gas, steam, and electric piping, etc., very seriously weakens some beams in the floor-arching or the wall, also that the ordinary hollow tile for floor-arches is peculiarly ill adapted for being cut through for piping.

In answer to a question from Mr. James Christie regarding the corrosion of iron buildings from the effect of the dampness in the brick and mortar, he said he had found no case where any iron section, resisting a strain was injured over $\frac{1}{2}$ per cent. of its effective section; but that where columns are used for leaders, or where there are pockets where water can collect and remain, the corrosion might be very serious.

Mr. Christie called attention to the probable inadequacy of the transverse bracing on many high metaliic buildings. For thin floors, substantial metallic plates of corrugated section are now used, having ample stiffness, with total vertical depth not exceeding $\frac{1}{30}$ of the span, and the weight of metal in the floor can be safely reduced to 15 pounds per square foot.

There was then a general discussion between the members as to the ordinary straight arch-tile for floors.

Mr. Constable took exception to the circle formed by the radius of arch-blocks being considered as representing the line of force in the arch, 1st, because a circular arc does not represent the line of pressure in the arch, and 2d, because the radius and bevel of these blocks is an assumption by the manufacturers for some special span, and is not varied to suit every span, additional blocks simply being added for increase of span. A simple rule for approximating the strength of these arches is to consider the load as concentrated in the middle, and to represent it graphically by the efficient depth of the block, and then to find what would be the resultant from the top of the arch down to the springing line where the arch-block bears against the iron beam. Then if there is enough cross-section of material to resist this resultant, the arch will stand.

Mr. Henrik V. Loss stated that the existing friction between the surfaces in action, undoubtedly made the arch act partly as a bearer, by preventing or offering resistance to any sliding action that otherwise would occur with joint lines not theoretically correct.

Mr. John C. Trautwine, Jr., described a fire-proof floor designed by E. D. Lindsey,

of New York, consisting of a wire netting suspended over two adjoining floor-beams and encased in a mass of light concrete containing plaster-of-Paris and sawdust.

Mr. Constable called attention to the very important consideration in all of the tile and concrete floors, of the effect of concentrated weight, such as is caused by a heavy safe resting on four wheels. (Mr. Trautwine suggests by letter that this difficulty might be obviated by placing under the safe an iron plate sufficiently large to receive all four feet and thus distribute the weight.)

Mr. Constable illustrated a floor that he had recently used, consisting of a series of arch-bars interlaced together and butting against a frame extension around the room. The triangular space between these bars was filled in by pressing an air-bag up from the other side, and casting a plaster-of-Paris arch over the bag, and when the plaster was set, removing the bag; then on top of these bars and plastered arches filling in with ribs of fine concrete and then putting on the wooden or mosaic floor. He stated that he had got better results in ordinary brick arches, between beams, by placing the tie-rods close at the bottom flange of the beam instead of half way up, as is usual.

Mr. Trautwine brought before the Club a question respecting the position of the line of pressure in a flat arch consisting of a keystone, two blocks with parallel sides adjoining the keystone, and two end blocks between these last and the beams. One member, A, maintains that the line of pressure may be found by producing the sides of the keystone to meet in a line below the arch, and by drawing from a point in this line as a centre, two circular arcs from the top and bottom respectively of the bearing of the arch upon the beams. Another member, B, maintains that the position of the line of pressure must be found by the usual method of statics, and is entirely independent of such geometrical considerations, as is shown by the fact that we might as well find our centre by producing the parallel sides of the next two blocks.

Mr. John L. Gill, Jr., supported A's position, drawing a more nearly correct sketch of the construction, and further criticised the character of the materials used, and the manner of putting them together.

Mr. Constable claimed that B was right, pointing out that the line of pressure in an arch is not in any case a circular arc.

Mr. T. H. Lüders held that the line of pressure must pass through the extrados at the centre and through the intrados at the skewbacks.

ABSTRACT OF MINUTES OF THE BOARD OF DIRECTORS.

JANUARY 7, 1893.—Present: Vice-President F. H. Lewis, Directors John E. Codman, George V. Cresson, Strickland L. Kneass, Wilfred Lewis, H. W. Spangler and David Townsend.

The Finance Committee presented the Treasurer's trial balance for December, which showed the cash on hand January 1, 1893, to be $299.24, and the contributions to the World's Fair Fund to date to be $369.00. It was moved and carried that the Treasurer be authorized to turn over to the retiring President the subscriptions to the Chicago Fund, the latter to act as trustee for the Club.

JANUARY 14, 1893.—Present: President James Christie, Vice-President F. H. Lewis, Directors John E. Codman, Strickland L. Kneass, Wilfred Lewis and David Townsend, also the Treasurer and the Secretary.

Mr. F. H. Lewis presented the draft for the Annual Report of the Board of Directors, which was ordered to be revised by Mr. Townsend and the Secretary.

The Treasurer presented a draft of his Annual Report, and he was directed to distinctly separate the expenses incurred in 1891 from those incurred in 1892, and to enter items in detail, that the Club might understand how the money had been spent. It was moved and carried that an abstract of the Treasurer's Report be incorporated in the Report of the Board.

JANUARY 21, 1893.—Present: President James Christie, Vice-President F. H. Lewis, Directors John E. Codman, George V. Cresson, Strickland L. Kneass, Wilfred Lewis and David Townsend, also the Treasurer and the Secretary.

The Treasurer read his Annual Report as revised, and it was accepted for presentation at the Annual Meeting of the Club.

The Publication Committee presented estimates that had been received from the Times Printing House and from Sherman & Co., for printing the Records and Notices of Meetings. The Committee was authorized to use its own judgment in the matter.

JANUARY 28, 1893.—Present: President John Birkinbine, Vice-President James Christie, Directors Strickland L. Kneass, John L. Gill, Jr., Henry J. Hartley and W. B. Riegner, also the Secretary.

It was moved and carried that the Secretary prepare an order of business for Board Meetings, and submit the same for approval at the regular meeting on February 18th.

The Publication Committee reported that they had received other estimates for printing the Club Records and Notices of Meetings, some of which were lower than the price now paid the Globe Printing House. It was the opinion of the Board that the Committee should make the best financial arrangement with regard to this, and they were instructed to act according to their own judgment in the matter.

The resignation of Director David Townsend was presented and accepted with regret. On motion, Mr. Wilfred Lewis was nominated and unanimously elected to fill the vacancy.

The President then appointed the following Committees, the first named in each case being Chairman:

Finance.—Messrs. Gill, Christie and Spangler.

Membership.—Messrs. Riegner, F. H. Lewis and Christie.

Publication.—Messrs Kneass, W. Lewis and Gill.

Library.—Messrs. Spangler, Hartley and Riegner.

House.—Messrs. F. H. Lewis, Hartley and Riegner.

Information.—Messrs. W. Lewis, Kneass and F. H. Lewis.

The President suggested that the Entertainment Committee invite Professor Rothrock to read a paper on a Forestry subject before the Club, and that later, papers might be requested from Major Chas. W. Raymond and others, on important engineering work in which they might be engaged. He also suggested the advisability of inviting exhibits of interesting products and inventions, and of having reception meetings to influential engineers who would read papers before the Club previous to the reception, to which members could invite their friends upon cards provided by the Club. He thought that a considerable income might be obtained by the Library Committee offering back numbers of the Proceedings to members at reduced rates.

Upon motion of Mr. Kneass it was directed that the Secretary invite the alumni of the Rensselaer Polytechnic Institute to use the Club House during their coming meeting in Philadelphia.

The President appointed Mr. Henrik V. Loss Alternate Teller in place of Mr. John S. Mucklé, declined.

February 18, 1893.—Present: President John Birkinbine, Vice-Presidents F. H. Lewis and James Christie, and Directors John L. Gill, Jr., Henry J. Hartley, Wilfred Lewis, W. B. Riegner and H. W. Spangler.

The Report of the Finance Committee for the month of January was read and filed.

On recommendation of the House Committee, the salary of the janitor was made $20 per month, to date from January 1st.

Mr. Birkinbine laid before the Board a request from Mr. E. L. Corthell, asking the Club to endorse a request for an appropriation by Congress for the publication of papers presented at the various World's Fair Congresses held in Chicago during 1893. No action. He also presented a letter from Mr. Corthell in regard to the reception of visiting French Engineers during the World's Fair. No action was taken, but it was the sense of the Board that the President should reply that the Club would do its part in the matter when the occasion arrived.

March 18, 1893.—Present: Vice-Presidents F. H. Lewis and James Christie, Directors Strickland L. Kneass, H. W. Spangler, John L. Gill, Jr., Henry J. Hartley, W. B. Riegner and Wilfred Lewis, also the Secretary.

The House Committee was directed to order invitation cards for sending to non-members, and a duplicate whist outfit, and also to raise the periodical case in the reading-room.

The House Committee reported that the front third-story room could be fitted up with billiard table, etc., for about $200.00.

The Information Committee reported that they had purchased a lantern from Professor Rothrock for $40, and took the liberty of doing it without the authorization of the Board, as they had been able to obtain a $70 lantern, nearly new, by prompt

action. The purchase was approved, and the Committee authorized to procure a suitable screen for use with the lantern.

The Library Committee was authorized to subscribe for the *Official Railway Guide*, *Puck* and *Judge*.

April 15, 1893.—Present: Vice-President James Christie, Directors Strickland L. Kneass, H. W. Spangler, John L. Gill, Jr., Henry J. Hartley and W. B. Riegner, also the Secretary.

The following order of business was adopted for Board Meetings:

1. Reading of minutes of previous meeting.
2. Reports of officers:
   - (*a*) President.
   - (*b*) Treasurer.
   - (*c*) Secretary.
3. Reports of Committees:
   - (*a*) Finance Committee.
   - (*b*) Membership Committee.
   - (*c*) Publication Committee.
   - (*d*) Library Committee.
   - (*e*) House Committee.
   - (*f*) Information Committee.
4. Old Business.
5. New Business.
6. Adjournment.

A letter was read from the Committee of Fifty for a new Philadelphia, requesting the appointment of a sub-Committee of three to represent this Club in the Union Committee to procure an authoritative expression of public opinion with regard to water-supply, street-cleaning, etc. This was ordered to be referred to the Club for action.

The Report of the Treasurer for the month of March was presented and ordered filed.

Mr. Kneass presented a list of the 154 subscribers to the Chicago Fund, showing $642.00 paid in, $13 still due, and $30 that had been offered if extra subscriptions were necessary, and he stated that a special appeal had been sent to each member of the Club who had not yet subscribed.

The Secretary was directed to correspond with Mr. Cloud, stating that the Club was prepared to send $500.00 of its assessment for the support of the Engineering Headquarters at Chicago, and inquiring what privileges this would entitle the Club to, and whether those privileges would be restricted to only those members who had subscribed.

May 11, 1893.—Present: President John Birkinbine, Vice-President James Christie, Directors Spangler and Riegner, and the Secretary.

Upon motion the Treasurer was directed to send a personal letter to each member indebted to the Club, with the next monthly statement, asking for prompt settlement of accounts, to assist in decreasing the present indebtedness of the Club.

It was ordered that at the meeting of May 20th, the President's suggestions with regard to the appointment of a Reception Committee to assist foreign visiting engineers in inspecting points of interest in this city, and the scheme of bonding the Club's indebtedness among its members, should be considered.

The Finance Committee was authorized to give the Globe Printing House the Club's four months' note for $300, in partial settlement of their account.

MAY 20, 1893.—Present: Vice-President F. H. Lewis, Directors H. W. Spangler, John L. Gill, Jr., W. B. Riegner and Wilfred Lewis, also the Secretary.

The Finance Committee reported the Assets and Liabilities of the Club, with comment upon the account of the Globe Printing House, and upon motion it was ordered that the Treasurer be directed to give the latter a four months' note for $300 in part payment thereof.

The Treasurer's Report for April was presented and accepted.

The House Committee reported that an ash-barrel and coal hods were badly needed, and upon motion, the janitor was authorized to procure them. The Committee also reported estimates received for fitting up billiard room and rooms on the fourth floor. These were laid on the table. They presented a notification received from Mr. Cavin, Agent Girard Estate, that the rent of the Club House would be increased to $1,100 per year from July 1st. This was referred back to the Committee to investigate the rents of neighboring properties, and see if the increase could be prevented for next year.

Mr. E. V. d'Invilliers was appointed Alternate with Mr. Strickland L. Kneass to represent the Club at the One Hundred and Fiftieth Anniversary of the American Philosophical Society.

The Secretary presented a communication from Mr. Harlow, of Pittsburg, requesting action by the Club upon a bill to be brought before the legislature for the appointment of a Commission of nine citizens to examine and report upon the cause of pollution of the water supplies of the principal cities of the State. The Secretary was instructed to acknowledge its receipt, and to say that it would be considered later.

JUNE 3, 1893.—Present: President John Birkinbine, Vice-President James Christie, Directors John L. Gill, Jr., W. B. Riegner and Wilfred Lewis, also the Secretary.

At the request of Mr. F. H. Lewis, the correspondence with regard to increased rental from July 1st was presented, and it was decided that it would be best for the Club to accept the increase, if personal efforts with the members of the Board of City Trusts, which some of the members of the Club volunteered to make, were unsuccessful in securing continuance at the present figure.

The House Committee was instructed to have the Club House put in good sanitary condition, hiring additional help for the purpose if they considered it necessary.

JUNE 17, 1893.—Present: President John Birkinbine, Directors Strickland L. Kneass, H. W. Spangler, John L. Gill, Jr., W. B. Riegner and Wilfred Lewis, also the Secretary.

A letter from Mr. Cavin, Agent Girard Estate, dated 14th inst., with reference to increase of rent, was read, and upon motion, the new figure was accepted, and the House Committee directed to confer about necessary repairs to the house.

The Chair announced that he would like each Committee to present a report at the first Fall meeting, and he suggested that extra copies of the Proceedings might advantageously be distributed for advertising purposes. Upon motion, the Publication Committee was authorized to carry out the latter suggestion.

The Treasurer's Report for May was presented and accepted.

Upon motion, the Treasurer was directed to send a second subscription of $350 to Chicago for the support of the Engineering Headquarters, making the total amount contributed $850.

ABSTRACT OF MINUTES OF THE CLUB.

Business Meeting, January 7, 1893. — President James Christie in the chair. Fifty-two members and visitors present.

It was moved and carried that the amendment to Article VII, Section 2, as proposed, should apply to the dues for 1894.

Upon request, Mr. Wilfred Lewis explained that the present dues were insufficient to meet the Club's expenses and an increase therefore seemed necessary, and should properly come from those who are most benefited, viz., the resident members and associates.

It was moved and carried that the Board of Directors appoint a delegate to attend the celebration of the One Hundred and Fiftieth Anniversary of the American Philosophical Society.

Mr. E. V. d'Invilliers, Chairman of the Committee appointed to draft a suitable memorial on the death of Mr. Joseph N. DuBarry, active member, presented a Memorial.

In answer to questions from various members, it was explained that for the Engineering Congress and Headquarters at the World's Fair, the Engineers' Club had been assessed $1,000, and although it was considered impossible for the Club to raise this amount, in view of the fact that many members had already contributed through the national engineering societies, the opinion of the meeting was that it would be very desirable for every member to do what he could to bring the contribution as near that figure as possible.

Professor Angelo Heilprin gave a very interesting address on "The Scientific Results of the Peary Expedition" illustrated by photographs projected by the lantern.

Mr. Chas. S. Churchill, through the Secretary, presented a further discussion on High Speed on Railways, which was referred for publication.

Fifteenth Annual Meeting, January 21, 1893.—President James Christie in the chair. Fifty-two members and visitors present.

The Board of Directors reported for the fiscal year 1892, that: —

The most important event in the history of the Club during the past year was the acquisition of a Charter.

The Board feel that it is their duty before retiring from office to make some explanation of the proposed amendment to the By-Laws increasing the dues of resident members and associates from $10.00 to $15.00 per annum.

For a number of years past there has been a deficit at the close of each year, which has accumulated from year to year until it amounted to the sum of $508.56 on January 1, 1892.

No unnecessary expenditures have been made, and there has been a net saving over previous years of more than $200.00, and a further curtailment has been made which will effect an additional saving of $185.00.

The books of the Club show that the deficit on January 1, 1893, amounts to $934.42, an increase of $430.86 for the year.

The present Board have used every means in their power to decrease this indebtedness, and to this end issued, under date of June 16, 1892, a circular letter to the members, asking them to use their best endeavors to increase the membership, and setting forth the advantage of a connection with the Club. The effect of this circular may be judged when it is stated that from June 16th to January 1st, 1893, the membership was increased by twenty-one Active and one Associate Members, while in the months from January 1st to June 16th, previous to issuing the circular, the membership was increased by forty-three Active and two Associate Members.

It is the judgment of the Board, therefore, that while it would not be impossible for the Club to meet its running expenses by strict economy, with the dues at $10.00, it is their unanimous opinion that this would not be the best policy for the Club to pursue. On the contrary, they believed that the Club can only be strengthened in influence and membership by an increase in facilities for the advancement, social and otherwise, of the interests of its members. At present, the Proceedings, although nearly self-supporting, are considerably hampered for funds, and many desirable features for the promotion of interest and activity in Club affairs, which have been contemplated by the Board, would be made available by an increase in revenue.

Another important feature of the year has been the careful revision of the By-Laws by a Committee of the Board, making them conform to the requirements of the Charter.

The list of members at the close of 1892 stood as follows:

	RESIDENT.	NON-RESIDENT.	TOTAL.
Honorary	0	1	1
Active	264	177	441
Associate	12	3	15
	276	181	457

The Treasurer's Annual Report showed receipts for 1892 amounting to $6,377.10, and expenditures for the same period, $6,077.86, leaving a cash balance, January 1, 1893, of $299.24. Of the above noted expenditures, $1,222.00 was incurred prior to 1892.

The statement of the financial condition, January 1, 1893, showed Assets amounting to $1,124.74, and Liabilities, as far as known, amounting to $2,059.16, leaving a deficit, January 1st, 1893, of $934.42.

The Tellers reported that 92 legal votes had been cast for each of the following officers, who were therefore declared elected:

President:
JOHN BIRKINBINE.

Vice-President:
JAMES CHRISTIE.

Treasurer:
T. CARPENTER SMITH.

Secretary:
L. F. RONDINELLA.

Directors:
HENRY J. HARTLEY,
JOHN L. GILL, JR., W. B. RIEGNER.

The Secretary read an Act relative to a Forestry Commission.

Mr. Strickland L. Kneass, Chairman of the Publication Committee, called the attention of the meeting to the custom of the Board and its Publication Committee to regard papers presented at the meetings as the exclusive property of the Club, and not to be given for publication in technical journals until they had appeared in the Proceedings; and the Committee thought that if the Proceedings were issued as regularly as they came out last year, the members would be willing to wait a short time rather than have their papers published elsewhere.

Business Meeting, February 4, 1893.—President John Birkinbine in the chair. Forty members and visitors present.

The tellers reported that 128 legal votes were cast on the proposed amendment to Article VII, Section 2, paragraph 1, of the By-Laws, of which 77 were for the amendment and 51 against it.

As 86 votes were necessary to carry the amendment, it was declared lost.

The Secretary read five letters that had been received, expressing the opinions of their writers as to whether papers should be given to engineering journals before they had appeared in the Proceedings of the Club, four of which were opposed to such action while the fifth favored it.

The general opinion was that the Proceedings should be issued promptly in order that the papers might appear as soon after they had been read as possible, and that simultaneously with their appearance in the Proceedings they might be given to the technical journals.

The Secretary read a communication from Mr. Horace W. Sellers, transmitting to the Club a copy of a paper presented by Mr. H. F. J. Porter, at the last meeting of the American Society of Mechanical Engineers, referring to the status of the engineering profession.

Dr. Henry Leffmann presented the paper of the evening on "The West Sterilizer for Water and Milk," illustrating his remarks by the projecting lantern and by means of the apparatus itself.

Regular Meeting, February 18, 1893.—President John Birkinbine in the chair. Sixty-eight members and visitors present.

Mr. S. M. Vauclain read a paper on "The Baldwin Four-cylinder Compound Locomotive," illustrated by lantern slides and a model working under steam.

Business Meeting, March 4, 1893.—President John Birkinbine in the chair. Fifty members and visitors present.

Professor Joseph T. Rothrock made the address of the evening on "Wood-structure in its Relation to Mechanical Purposes," with the aid of photographs and sections of wood, projected by the lantern.

Regular Meeting, March 18, 1893.—Vice-President James Christie in the chair. Fifty-five members and visitors present.

Mr. Geo. S. Webster exhibited, by means of the projecting lantern, a series of photographs of all the important bridges in Philadelphia that had been built by the City Survey Department, and described their principal dimensions and interesting engineering features.

The Chair announced that a table d'hôte dinner, such as had been served to members at the last meeting, would be continued on the dates of future meetings if 14 members would subscribe to the same in time to give the necessary orders.

Regular Meeting, April 1, 1893.—Vice-President James Christie in the chair. Forty members and visitors present.

The Secretary read a paper by Mr. Pierre Giron, on "The Various Systems of Burning Portland Cement," which was referred for publication. The paper was discussed by Messrs. Lesley, Whitaker, Christie, Hartranft and Webster.

Regular Meeting, April 15, 1893.—Vice-President James Christie in the chair. Thirty-four members and visitors present.

Mr. Edward K. Landis read a paper on "The Development of the Tilly Foster Iron Mine," in which he gave a brief historical account of the possession and early working of the property, and a detailed description of its more recent development.

Mr. Pierre Giron further discussed "The Burning of Portland Cement."

Business Meeting, May 6, 1893.—President John Birkinbine in the chair. Forty-two members and visitors present.

The Committee appointed presented a "Memorial of W. W. Thayer."

The President was authorized to appoint three delegates, including himself, to represent the Club in a Union Committee on Water Supply, Sanitation, etc.

President Birkinbine referred to some of the engineering features which impressed themselves upon him during a recent trip in Mexico.

The Secretary read a paper on "The Various Systems of Grinding Cement," by Pierre Giron, in which the author called attention to the qualities of the burnt product of the Portland cement kiln, and the desirability of reducing the clinker to a fine powder. The paper was discussed by Messrs. Lesley, Comfort, Whitaker, Webster, Landis and others.

Regular Meeting, May 20, 1893.—Vice-President F. H. Lewis in the chair. Thirty-three members and visitors present.

The rules prevailing among architects and builders for vertical pressures that can be safely borne by high masonry walls, and the load for ball bearings, were briefly discussed by several members (see Notes and Communications).

Business Meeting, June 3, 1893.—President John Birkinbine in the chair. Thirty-two members and visitors present.

The President was directed to appoint a Committee, including himself, to make arrangements to assist in directing visiting engineers to the best places for them to inspect in the different branches of engineering work, and to entertain them in any other possible way.

Mr. Gill, as Chairman of the Finance Committee, stated that he thought it would probably be a very bad time of year to act upon bonding the Club's indebtedness at present, but that something would have to be done in the Fall in order to enable the Club to conduct its business without being hampered by the constant shortness of funds.

Upon motion, the matter was referred to the Finance Committee to formulate and report a plan.

The paper on Cement, by Mr. Giron, was again brought up for discussion by Mr. Thomas D. Whitaker.

Mr. Wilfred Lewis stated that he had suggested to the President the advisability of visiting the works of the Wellman Iron and Steel Company, at Thurlow, on the afternoon of the day of our next meeting, Saturday, June 17th.

The discussion on improving the present status of the engineering profession was opened by the Secretary reading, at the request of Mr. Horace W. Sellers, a paper by Mr. H. F. J. Porter, before the American Society of Mechanical Engineers, which was discussed by Messrs. Birkinbine and Price.

Business Meeting, June 17, 1893.—President John Birkinbine in the chair. Fifty-three members and visitors present.

Mr. C. H. Roney opened a verbal discussion on "Modern Office Buildings," and the subject was further discussed by Messrs. Constable, Christie, Loss, Trautwine, Gill and Lüders.

PROCEEDINGS

OF THE

ENGINEERS' CLUB OF PHILADELPHIA

ERRATA.

Vol. X, No. 1, p. 3, line 13, for $\phi P \frac{2}{3} \frac{R^3 - r^3}{R - r}$ read $\phi P \frac{2}{3} \frac{R^3 - r^3}{R^2 - r^2}$.

Vol. X, No. 3, p. 217, line 15, from bottom, "The Burning of Portland Cement," Mr. Lesley's discussion, for "per cent." read "cents."

conclusions reached by the Professor, and which Mr. Loss has just exhibited and made use of, without criticism and without pointing out the manner in which they have been arrived at. I shall therefore substantially lay before you and criticise the Professor's investigation, with only such modifications of the purely mathematical treatment of the matter as I have found possible

* This paper formed part of the general discussion on Ball Bearings referred to in Vol. X, No. 3, page 245.—*Publication Committee.*

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The discussion on improving the [illegible]

PROCEEDINGS

OF THE

ENGINEERS' CLUB OF PHILADELPHIA

ORGANIZED DECEMBER 17, 1877.

NOTE.—The Club, as a body, is not responsible for the statements and opinions advanced in its publications.

Vol. X.] OCTOBER, 1893. [No. 4.

XIII.

REVIEW OF PROF. GRASHOF'S INVESTIGATION OF THE CARRYING CAPACITY OF ROLLERS AND BALLS.*

By CARL G. BARTH, Active Member of the Club.

Read May 20, 1893.

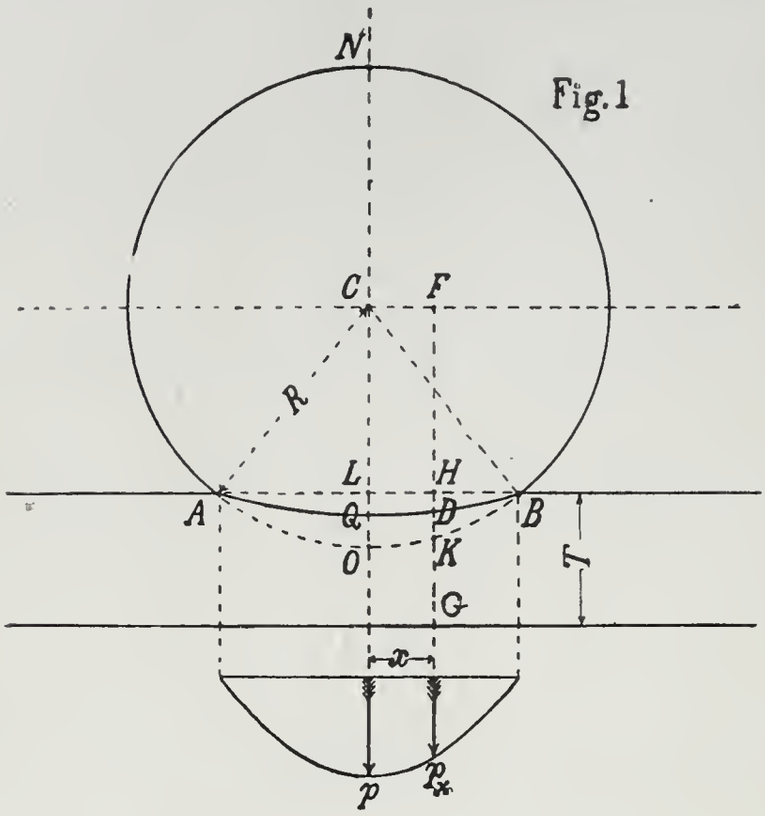
HAVING a copy of Prof. Grashof's work, "*Theorie der Elasticität und Festigkeit*," just referred to by Mr. Loss, and remembering that it contained an investigation of the carrying capacity of rollers and balls, I undertook to familiarize myself with the same when I learned that this subject would come before the Club this evening.

In so doing I found, however, that I could not agree with the conclusions reached by the Professor, and which Mr. Loss has just exhibited and made use of, without criticism and without pointing out the manner in which they have been arrived at. I shall therefore substantially lay before you and criticise the Professor's investigation, with only such modifications of the purely mathematical treatment of the matter as I have found possible

*This paper formed part of the general discussion on Ball Bearings referred to in Vol. X, No. 3, page 245.—*Publication Committee.*

and desirable, in order to avoid the calculus employed by the Professor, and thereby simplify the demonstration.

The Professor proceeds about as follows:



A solid cylindrical roller of length l and radius R lies with its axis in a horizontal position on a horizontal straight plate of uniform thickness T, which again rests on a fixed, unyielding horizontal plane. Let P be the pressure the roller exerts against the abutment plate, on account of its own weight and other loading. Due to the elasticity of the materials the contact will not be along a line only, but along a narrow surface, in which the intensity of pressure p_x constantly increases from zero along its two parallel edges to a certain maximum p along its center line. Let the problem be to find the relations existing between P, p, R, T and l, when the moduli of elasticity of the roller and the abutment plate are respectively E_r and E_t.

In Fig. 1, which represents a section perpendicular to the axis of the roller, C is the center of the cross-section of the roller and AB the greatly exaggerated width of the surface of contact. The cross-section of the contact surface is a certain flat arc $A\ Q\ B$, subtended between the straight line $A\ L\ B$ and the circular arc $A\ O\ B$ of radius R. Let K be any point on this circular arc at the distance x from the vertical center line $O\ N$.

If we draw through K a vertical line $F\ K\ G$ and denote by r_x that part of it, $K\ D$, which falls between the circular arc $A\ O\ B$ and the cross-section $A\ Q\ B$ of the contact surface, and by t_x that part of it, $H\ D$, which falls between the straight line $A\ L\ B$ and the arc $A\ Q\ B$, then r_x and t_x are evidently the respective

compressions of the roller and the abutment plate at the point D at the distance x from the vertical center line $O\,N$.

If we now suppose that the effect of r_x penetrates proportionally to the point F in the central horizontal section of the roller, as a specific compression $\frac{r_x}{R}$, and that the effect of t_x penetrates proportionally to the point G in the bottom surface of the abutment plate, as a specific compression $\frac{t_x}{T}$, then the intensity of pressure at D will be

$$p_x = E_r \frac{r_x}{R} = E_t \frac{t_x}{T}, \text{ or}$$

$$r_x = p_x \frac{R}{E_r} \text{ and } t_x = p_x \frac{T}{E_t}, \text{ and hence}$$

$$r_x + t_x = H\,K = p_x \left(\frac{R}{E_r} + \frac{T}{E_t}\right), \text{ giving}$$

$$p_x = \frac{H\,K}{\frac{R}{E_r} + \frac{T}{E_t}}, \text{ the maximum value of which is}$$

$$p = \frac{L\,O}{\frac{R}{E_r} + \frac{T}{E_t}}, \text{ from which } L\,O = p\left(\frac{R}{E_r} + \frac{T}{E_t}\right).$$

This shows that the intensity of pressure in the contact surface is everywhere proportional to the ordinate $H\,K$ of the circular arc $A\,O\,B$, and hence the total vertical pressure in the contact surface will bear the same ratio to the volume of the segmental slice $A\,L\,B\,O \times l$ of the roller, as the intensity of pressure p_x bears to the ordinate $H\,K$. But the circular segment $A\,L\,B\,O$ can without any perceptible error be figured as a parabolic segment $= \frac{2}{3}\,L\,O \cdot A\,B$, where $A\,B = 2\sqrt{L\,N \cdot L\,O}$, which again without appreciable error can be written

$$A\,B = 2\sqrt{2\,R \cdot L\,O}.$$

The total vertical pressure in the contact surface can therefore be written:

$$P = \frac{p_x}{HK} \times \tfrac{2}{3}\,LO \cdot AB \times l = \frac{p}{LO} \times \tfrac{2}{3}\,LO \cdot 2\sqrt{2\,R \cdot LO} \times l$$

$$= \tfrac{4}{3}\,p\sqrt{2\,R\,p\left(\frac{R}{E_r} + \frac{T}{E_t}\right)}\,l = \frac{4\sqrt{2}}{3}\,p^{\frac{3}{2}}\sqrt{R\left(\frac{R}{E_r} + \frac{T}{E_t}\right)}\,l.$$

For a solid ball of radius R resting on a plate of thickness T and sustaining a total load P_1, a similar consideration will give

$$P_1 = \pi\, p^2\, R \left(\frac{R}{E_r} + \frac{T}{E_t}\right).$$

The suppositions made the basis of these investigations are, however, not altogether correct, in so far as the pressure in the contact surface, by its transmission on the one hand to the central horizontal section of the roller or ball, and on the other hand to the bottom surface of the abutment plate, will gradually spread over larger and larger areas, on account of the vertical compressions being accompanied by horizontal tensions and shearing stresses, which will even produce a swelling of the upper surface of the abutment plate and an increase of curvature of the roller or ball, in the neighborhood of the edges of the contact surface.

For this reason the compressions r_x and t_x will not extend into the two bodies as proportional, but as diminishing specific compressions, so that by E_r and E_t in the expressions derived for P and P_1 we must understand values, which can not without further ceremony be put equal to the known moduli of elasticity of the respective materials, but values which require a particular experimental determination, and which at the very most will be proportional to the moduli of elasticity. We may then write

$$P = C\, p^{\frac{3}{2}} \sqrt{R} \cdot l \text{ and } P_1 = C_1\, p^2\, R,$$

provided the constants $C = \frac{4\sqrt{2}}{3} \sqrt{\frac{R}{E_r} + \frac{T}{E_t}}$ and $C_1 = \pi \left(\frac{R}{E_r} + \frac{T}{E_t}\right)$ be determined by experiments.

These formulas are readily recognized as the same as those exhibited by Mr. Loss, the notation only being somewhat different, and made use of by him to show, what I hope to refute, that it is advantageous to use small rollers or balls in covering a certain size surface with them.

And hence the following criticism is submitted.

How the expressions $\frac{4\sqrt{2}}{3} \sqrt{\frac{R}{E_r} + \frac{T}{E_t}}$ and $\pi \left(\frac{R}{E_r} + \frac{T}{E_t}\right)$ have ever appeared to the Professor as constants, is certainly diffi-

cult to understand, as they contain no less than two variables, viz: R and T, and for this reason the Professor's final results are evidently worthless and can only have misled people, who have had blind confidence in the Professor's authority, to erroneously believe that the carrying capacity of a roller varies as the square root of its radius, and that of a ball as its radius direct.

If we, however, go back to the equations

$$P = \frac{4\sqrt{2}}{3} p^{\frac{3}{2}} \sqrt{R\left(\frac{R}{E_r} + \frac{T}{E_t}\right)}\, l \text{ and } P_1 = \pi\, p^2\, R\left(\frac{R}{E_r} + \frac{T}{E_t}\right),$$

they plainly show, as well as the Professor's whole investigation, that the carrying capacity of a roller or ball does not depend on the radius only, but also on the thickness of the abutment plate on which it rests. The only possibility of making a comparison between rollers or balls of various sizes appears therefore to be on the supposition, that they rest on abutment plates whose thicknesses vary as the radii of the rollers or balls.

On such a supposition, which is implied in putting $T = a\,R$ in these equations, they become

$$P = \frac{4\sqrt{2}}{3} p^{\frac{3}{2}}\, R \sqrt{\frac{1}{E_r} + \frac{a}{E_t}}\, l \text{ and } P_1 = \pi\, p^2\, R^2\left(\frac{1}{E_r} + \frac{a}{E_t}\right),$$

where the expressions $\sqrt{\frac{1}{E_r} + \frac{a}{E_t}}$ and $\left(\frac{1}{E_r} + \frac{a}{E_t}\right)$ are unquestionable constants for any assumed value of a, and hence we may now write

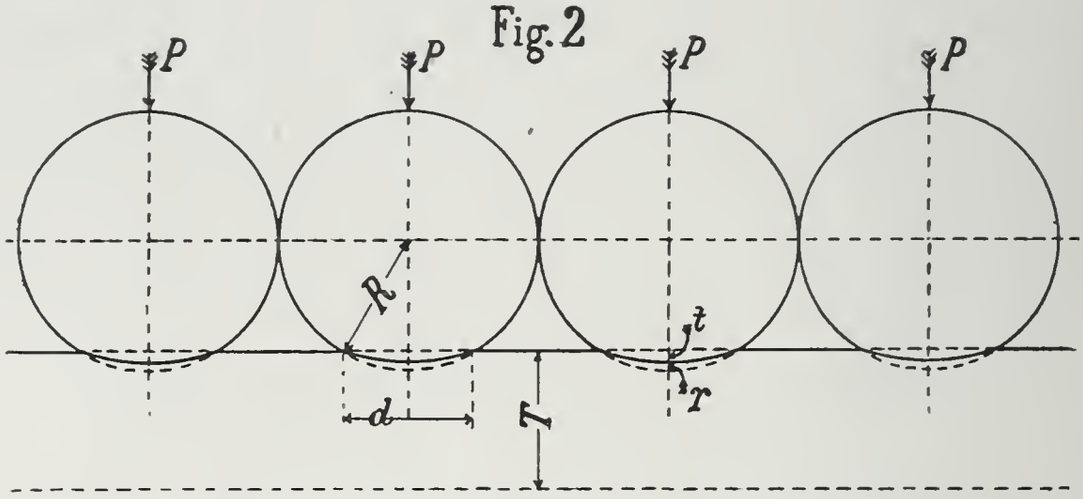
$$P = C\, p^{\frac{3}{2}}\, R\, l \text{ and } P_1 = C_1\, p^2\, R^2,$$

in which formulas C and C_1 must be determined experimentally in view of Prof. Grashof's very appropriate comments on the suppositions on which these results have been obtained.

According to these last results, the carrying capacity of a roller varies directly as its radius or diameter, and of course as its length, and that of a ball as the square of its radius or diameter. But this is the same as to say, that the total carrying capacity of a surface, completely covered with rollers or balls, is independent of the size of the rollers or balls, provided that, if large ones are used, the abutment plate is also proportionally thick; and let us now try to arrive at the same conclusions by a more direct process of reasoning, and on suppositions less ideal than those assumed by Professor Grashof.

To that end, suppose a surface of indefinite length, but of finite width l, completely covered by rollers, each carrying a pressure P. Let the radius of each roller be R and their length equal to the full width l of the surface. Suppose further that the abutment plate, whose top is that surface, is sufficiently thick to enable the total pressure to finally become, at least practically, uniformly distributed over its total horizontal section at a certain depth T, as it penetrates into it and gradually spreads over larger and larger areas. (Fig. 2.) Below this depth the yielding of the abutment plate will then, no matter how this is supported, have no other effect than a uniform lowering of its upper part with the rollers.

Fig. 2



Suppose also another, similar arrangement, in which the width of the indefinitely long surface and the length of the rollers are the same as in the first arrangement, but in which the radius R_1 of the rollers is a certain number of times larger, so that we may write $R_1 = a\ R$.

Let the pressure P_1, carried by each roller in the second arrangement, be just sufficient to cause the width d_1 of the contact surface between each roller and the abutment plate to also become a times the corresponding width d in the first arrangement, when we may also write $d_1 = a\ d$.

It is then pretty clear, that all other corresponding linear measurements in the two arrangements will also be in the ratio a to each other, so that the amount r_1 of maximum compression of each roller and the amount t_1 of maximum compression of the

abutment plate of the second arrangement will also be a times the same quantities r and t of the first arrangement, or $r_1 = a\ r$ and $t_1 = a\ t$.

The depth T_1, at which we will have uniform distribution of pressure in the abutment plate of the second arrangement, will then also be a times the same depth T in the first arrangement, and we can also write $T_1 = a\ T$. But we then get, what Prof. Grashof calls the diminishing specific compressions $\frac{r_1}{R_1}$ and $\frac{t_1}{T_1}$ equal to the evidently similarly diminishing specific compressions $\frac{r}{R}$ and $\frac{t}{T}$ respectively, as $\frac{r_1}{R_1} = \frac{a\,r}{a\,R} = \frac{r}{R}$ and $\frac{t_1}{T_1} = \frac{a\,t}{a\,T} = \frac{t}{T}$, and hence we must have just the same maximum intensity of pressure in the contact surfaces of the two arrangements.

In the same manner we must also have the same intensity of pressure at proportional distances from the center lines of the contact surfaces in the two cases, and that being the case, the total amount of pressure in each of the contact surfaces of the two arrangements must be to each other as the areas of those surfaces, or

$$P_1 : P = d_1\ l : d\ l = R_1 : R$$

That is, we have again that the pressures carried by the rollers in the two cases are proportional to their respective radii, for equal maximum intensity of pressure in the contact surfaces.

A similar consideration will also show the carrying capacity of balls to be proportional to the squares of their respective radii, so this truth may now be considered as pretty well established.

XIV.

THE GRINDING OF PORTLAND CEMENT.

By Pierre Giron, Active Member of the Club.

Well-burnt Portland cement, fresh from the kiln,* presents itself in the shape of black or greenish-black clinkers of great hardness and density. The agency of powerful machinery is required to bring these clinkers to the state of very fine powder. Even after the most thorough grinding, the powder is still gritty, feeling rough to the touch. This is caused by the presence of very fine grains which have not been ground to an impalpable powder. As the proportion of these grains decreases, the powder feels smoother.

The fineness of grinding was, until a few years ago, considered as a question of secondary importance by manufacturers and consumers. But it has become lately, and with reason, one of the essential requisites of slow-setting cements. As long as the quality of cement was controlled by the neat test only, little attention was paid to the fineness of grinding, which, in this case, exercises a small influence only. This subject received its first consideration in Germany. In testing mixtures of sand and cement, which test, after all, is the only one having any value from a practical standpoint, it was soon found that the strength of mortar increases in the proportion of the fineness of the cement. As cement is always used with an addition of sand, it became therefore a necessity to reduce to fine powder all the grains which were formerly inert and without value. This reform resulted in a great saving to the consumer, who does not get any more than 20 or 30 per cent. of matter which he can replace more cheaply with sand.

The following table illustrates very clearly the influence of fine grinding on the strength of mortars. This is taken from Caudlot page 330. The figures given in kilos per square centimeter have been changed to pounds per square inch.

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* See my paper on the Burning of Portland Cement. Vol. X., No. 3.

Residue on sieve.			Percentage of water in mixing.	Density of the briquettes.	Proportion of sand and cement.	Tensile strength per square inch.							Remarks.
No. 50.	No. 80.	No. 200.				7 days.	28 days.	3 months.	6 months.	1 year.	2 years.	3 years.	
0	0	25	11.	2.05	1:3	231	306	405	406	462	433	486	Briquettes made by pressing the mortar in the moulds, according to the European method of testing.
0	7.5	37	11.	2.03	1:3	184	284	290	314	400	390	441	
3	15	42	10.5	1.96	1:3	152	195	301	312	383	418	403	
16	30	50	10.5	1.89	1:3	113	164	202	220	230	357	348	
0	0	25	15.	1.86	1:3	115	209	248	272	311	318	384	Briquettes made to the consistency of mortar used in practical work according to the American method of testing.
0	7.5	37	15.5	1.87	1:3	64	169	207	220	284	292	374	
3	15	42	14.5	1.82	1:3	62	103	150	245	266	300	334	
16	30	50	14 5	1.85	1:3	50	107	142	173	208	284	289	
0	0	10	11.	2.14	1:3	2058	2940	3412	4361	4593	4834	5973	Tests for compressive strength.
0	0	25	11.	2.09	1:3	1606	2062	2773	3128	2713	3498	3640	
0	7.5	37	11.	2.10	1:3	1295	1720	2389	2559	2602	3199	3597	
3	15	42	11.	2.	1:3	1066	1521	1720	2033	2460	2502	2929	
16	30	50	11.	1.95	1:3	924	1351	1440	1395	1962	1777	2502	

To determine the fineness of any given brand of cement, three screens are necessary, Nos. 50, 80 and 200, and the residue of the cement can accordingly be divided into three parts: First, the coarse grains left on sieve No. 50; second, the fine grains passing No. 50, but retained on No. 80; third, the very fine grains passing No. 80, but retained on No. 200. The strictly impalpable portion of the cement can only be found by using a silk sieve. The most finely ground cements leave generally about 40 per cent. of residue on this sieve.

The elimination of the grains in cement could be accomplished without screens; by water, for instance. A known quantity of cement is diluted in a glass with a large quantity of water, and the whole well shaken. The coarse grains fall to the bottom, while the fine parts are floating. The water is changed and the

same operation repeated until the residue is perfectly neat and the water clear. But such tests, as that also of the silk sieve, are necessary only for special researches.

The inspection of the residue is interesting, as it gives a fairly accurate idea of the quality of the cement. The presence of particles of coal shows a careless selection of the clinkers. Yellow and soft grains come from imperfectly burnt parts. The grains should be hard, black and angular.

To illustrate the progress that has been made in the grinding of Portland cement, it is only necessary to recall that some years ago the best brands would generally leave from 8 to 10 per cent. of residue on No. 50 sieve, 15 to 20 per cent. on No. 80, and 40 to 50 per cent. on No. 200. Cements of the best quality are generally to-day so finely ground as to leave no residue on No. 50 sieve, 5 to 6 per cent. on No. 80, and only 25 to 30 per cent. on No. 200.

Although it is undoubtedly true that the value of cement is always increased the more finely it is ground, it must also be understood that the grains, after a certain size, are not necessarily inert. On the contrary, they are attacked by water in the course of time and form then active constituents in the mortar. Experiments have been made showing that the grains passing through No. 80 sieve, but left on No. 200, after having been kept in a glass of water for one year, formed a very hard body, as hard as any fine cement. The grains left on No. 80 sieve, but passing through No. 50, kept in the same conditions, formed an agglomerated mass, but without strength. The grains left on No. 50 sieve, after the same time in water, were not even agglomerated. A test was also made to determine the quantity of water combined with each of these samples. The first contained 10.26 per cent., the second 7.54 per cent., and the third 6.30 per cent. Neat cement contains at the end of a year about 10 or 11 per cent. of combined water. It is therefore certain that all the grains passing No. 80 sieve are thoroughly hydrated and contribute actively to the strength of the mortar.

The setting properties of cement are seriously influenced by fine grinding. The finer the cement, the quicker the setting. This is easily understood, since the active part proportionately

increases and the chemical reactions which take place during the setting are facilitated by the greater division of the material. With extremely fine and fresh cements, the rapidity of setting may be so increased as to become immediate. However, if the cement is of good quality, the setting becomes normal after a few days of seasoning. A cement of inferior quality might require a very long period of seasoning to correct this defect, but very fine grinding would, in this case, be especially important, in order to reduce to its minimum the danger of blowing, which is likely to exist in such cement.

The economy realized by the use of finely ground cement in making cheap mortars with a large proportion of sand, more than compensates for the extra cost of grinding. A coarsely ground cement mixed with 4 or 5 parts of sand would make a very stiff mortar, lacking plasticity and compactness; the least excess of water would wash out the cement powder. This difficulty is very much lessened with a finely ground cement, and owing to this fact, mortars are now made with proportions of sand which would have been impossible heretofore.

Having said this much of the necessity of fine grinding, it remains for me to describe by what means this end is accomplished, and what results we can expect from the improvements that have been recently made in this direction. I am aware that I am dealing here with one of the most difficult questions of practical manufacture, and one in which cement makers themselves show a great diversity of opinions. It is remarkable that so much progress has been made in the grinding of cement, not as the result of any new inventions, but rather as the natural development of old methods. The European factories which grind their cement so fine to-day do not differ materially from what they were twenty-five years ago. If cement making were carried on in this country with the same advantages that are possessed by foreign manufacturers, and if the present recognized standard of fineness were not established as the limit of what is possible, rather than what is desirable, then the safest course would be to follow closely the European practice. The necessity of keeping up with the progress made elsewhere has invited the mechanical ingenuity of many minds to produce new and superior means of

grinding. Even where these attempts have failed, they have, nevertheless, prepared the way for further action, and the problem of grinding cement by modern machinery is not considered now as hopeless as it used to be.

Through all the trials that have been made, one fact above all others appears well established, that to treat a material as obdurate as cement clinkers, it is necessary to proceed gradually. No machine can do the whole work in a single operation; on the contrary, the division of the work into stages will produce the best results.

The first operation consists in breaking up the large lumps of clinkers. For this, a jaw crusher of the Blake type is generally used. The highly crystalline texture of the material suits this machine very well, and one of comparatively small size will easily break up five or six tons an hour.

The size of the product of these crushers, generally from two to four inches, is still too large for the final operation of grinding, and an intermediate process is necessary to further disintegrate the material. This is done in most American cement mills by means of a pot-cracker or coffee-mill of small dimensions. The size of the product varies from one inch down. For finer crushing than this, this machine is neither well adapted nor economical. It is advantageously replaced in the best cement mills of Europe by large-sized rolls. This arrangement places the disintegration of the clinkers under better control, and delivers the material in a much more favorable condition for further grinding. The general use of crushing-rolls in other mining industries of this country will eventually lead to their adoption by cement manufacturers.

The final grinding is done almost universally with millstones. There is little to be said about this old and well-known process of grinding. The stones are extracted from a special quartz formation, and when ready for work are from four to five feet in diameter. They weigh over a ton each, and last about a year. The upper millstone runs at a speed of from 90 to 120 revolutions. The lower stone is stationary. The stones need dressing very frequently, their endurance depending on their hardness and the speed at which they are driven. When working under

favorable conditions, it may safely be estimated that millstones absorb from 30 to 35 H. P. for one ton of finished cement per hour.

The practice in America is somewhat different. The diameter of the millstone is smaller, not exceeding generally 40 inches. The upper stone is stationary, the lower one, called under-runner, revolves at a very high speed, sometimes above 300 revolutions. The different nature of the millstones in use here has caused these alterations from the ordinary practice. The cost of grinding Portland cement in this country with millstones is greater than in Europe, and the cement is not, as a rule, so finely ground.

The efforts made to supersede the millstone have resulted in the adoption by several cement works of Germany of the Jenisch Ball Mill, Figs. I. and II. This mill consists essentially of a

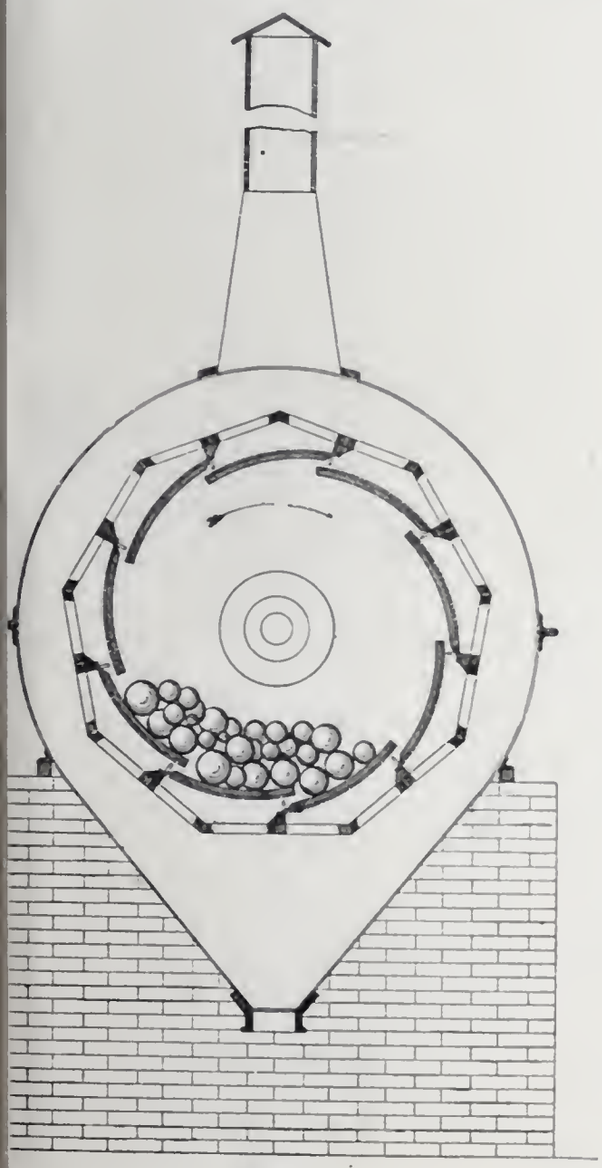

Fig. I.

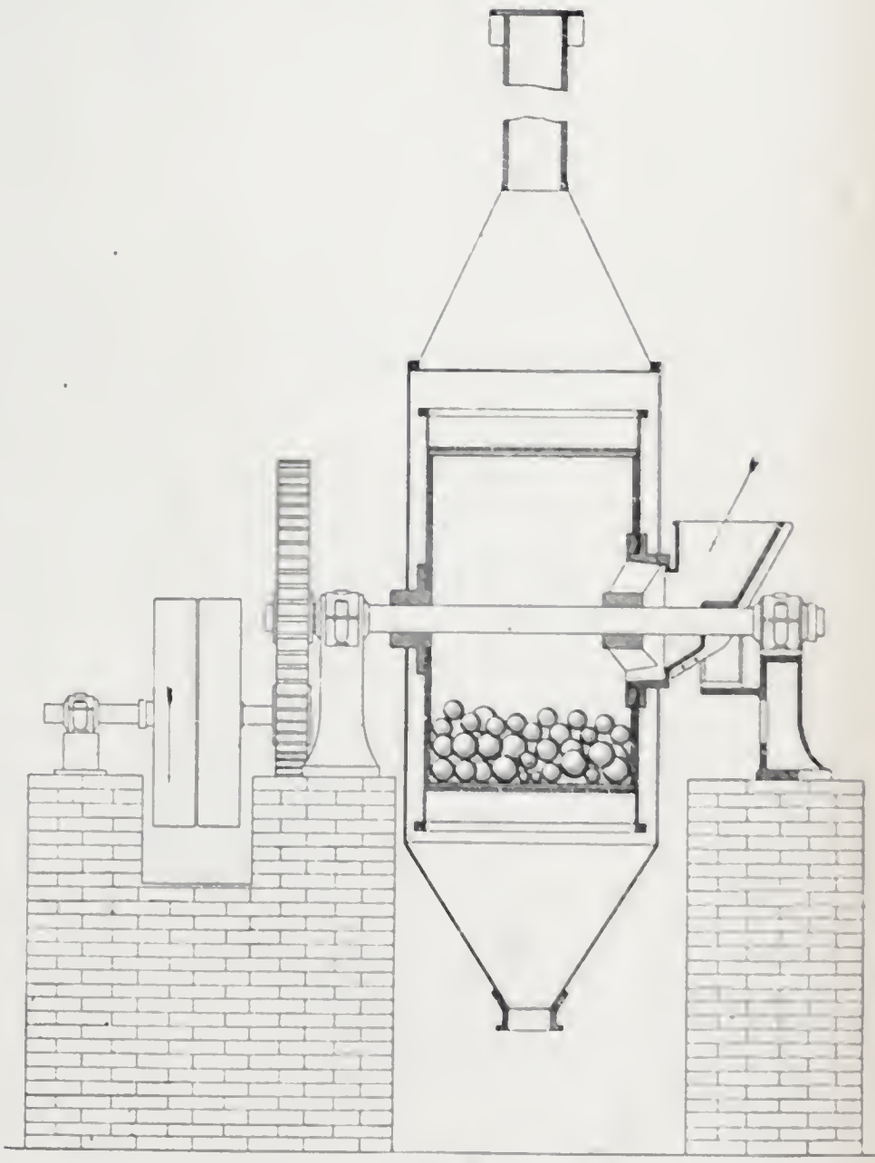

Fig. II.

revolving drum loaded with a large number of steel balls of various sizes. The material is introduced on the side of the mill, and becoming mixed with the balls, is ground to the desired fineness.

In this country, the Griffin Mill, in its improved form, Fig. III,

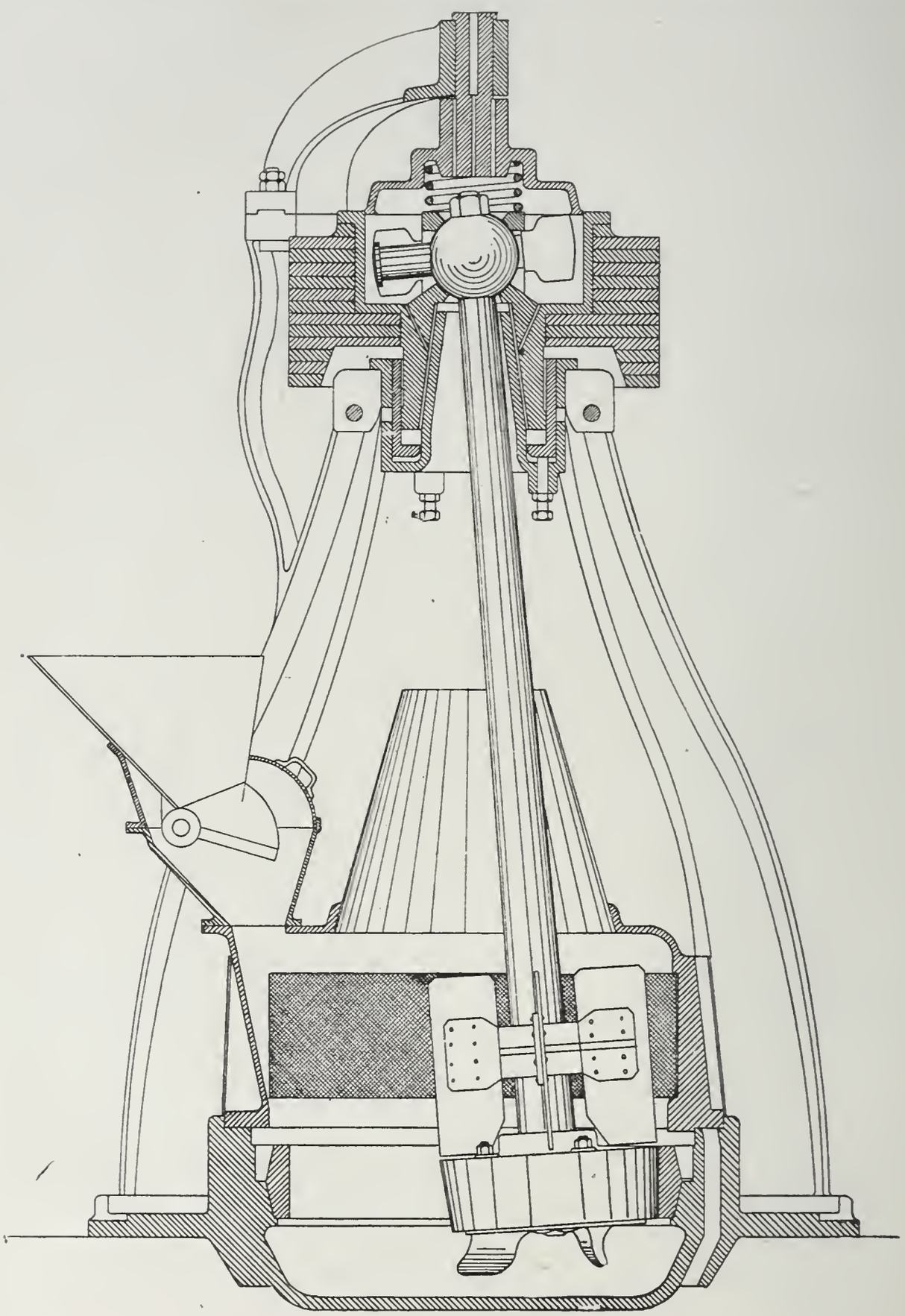

Fig. III.

has been adopted by some cement makers. In this mill, a heavy cylindrical roller, rigidly set on a vertical shaft from which it is hanging, revolves within a die against which the material is ground.

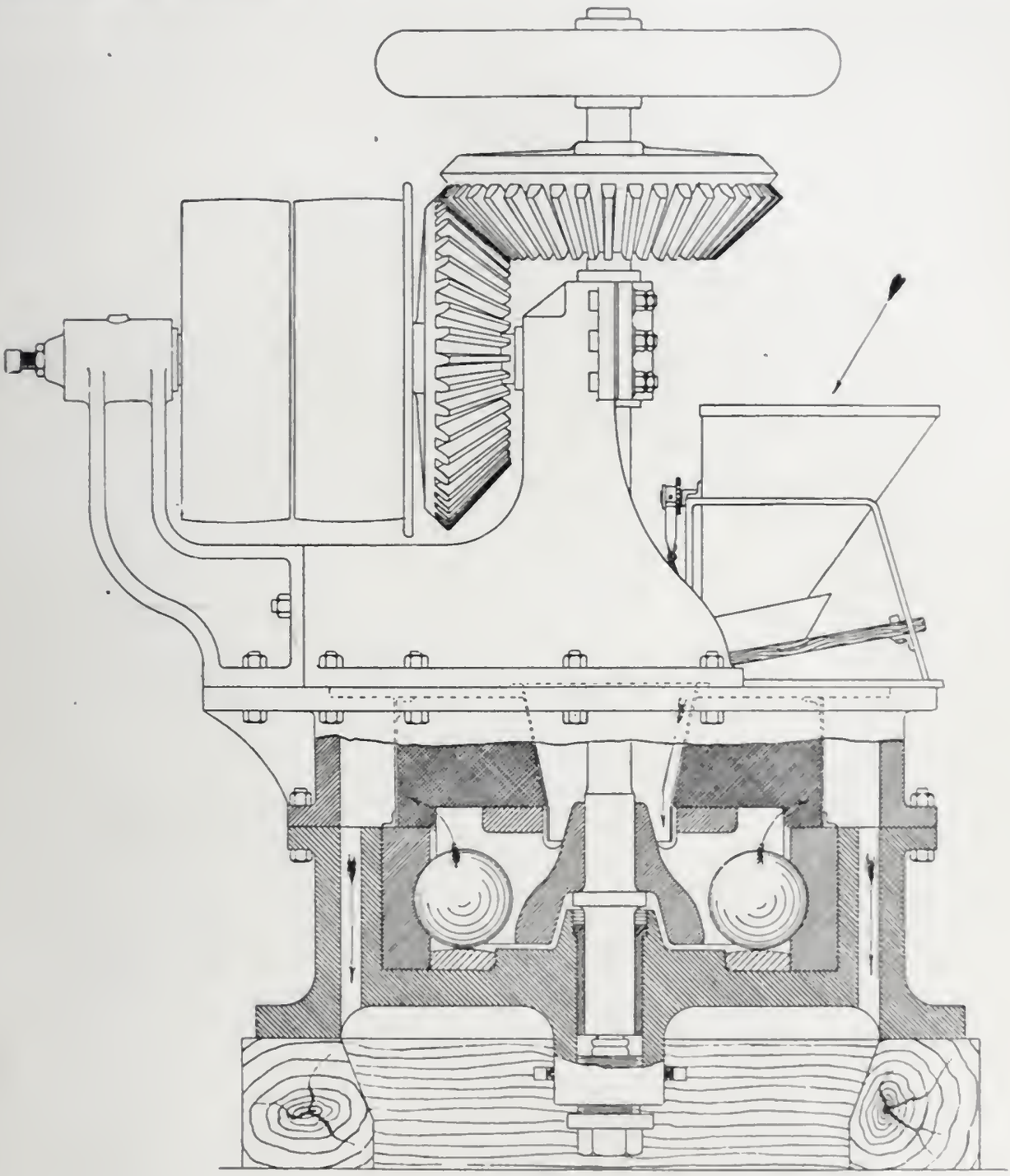

Fig. IV.

A successful grinding machine should necessarily possess certain advantages. First of all, its principle should be one capable of developing great power, as it is only by a high pressure or a heavy blow that impalpable dust will be produced. In its con-

struction, there are two important requirements: the mechanical arrangements should adapt it to the consumption of little power in producing a great effect, and the working parts should be capable of standing the severest action for an unlimited time. These conditions imply simplicity and massiveness.

I have found by experience that the pulverizers of the

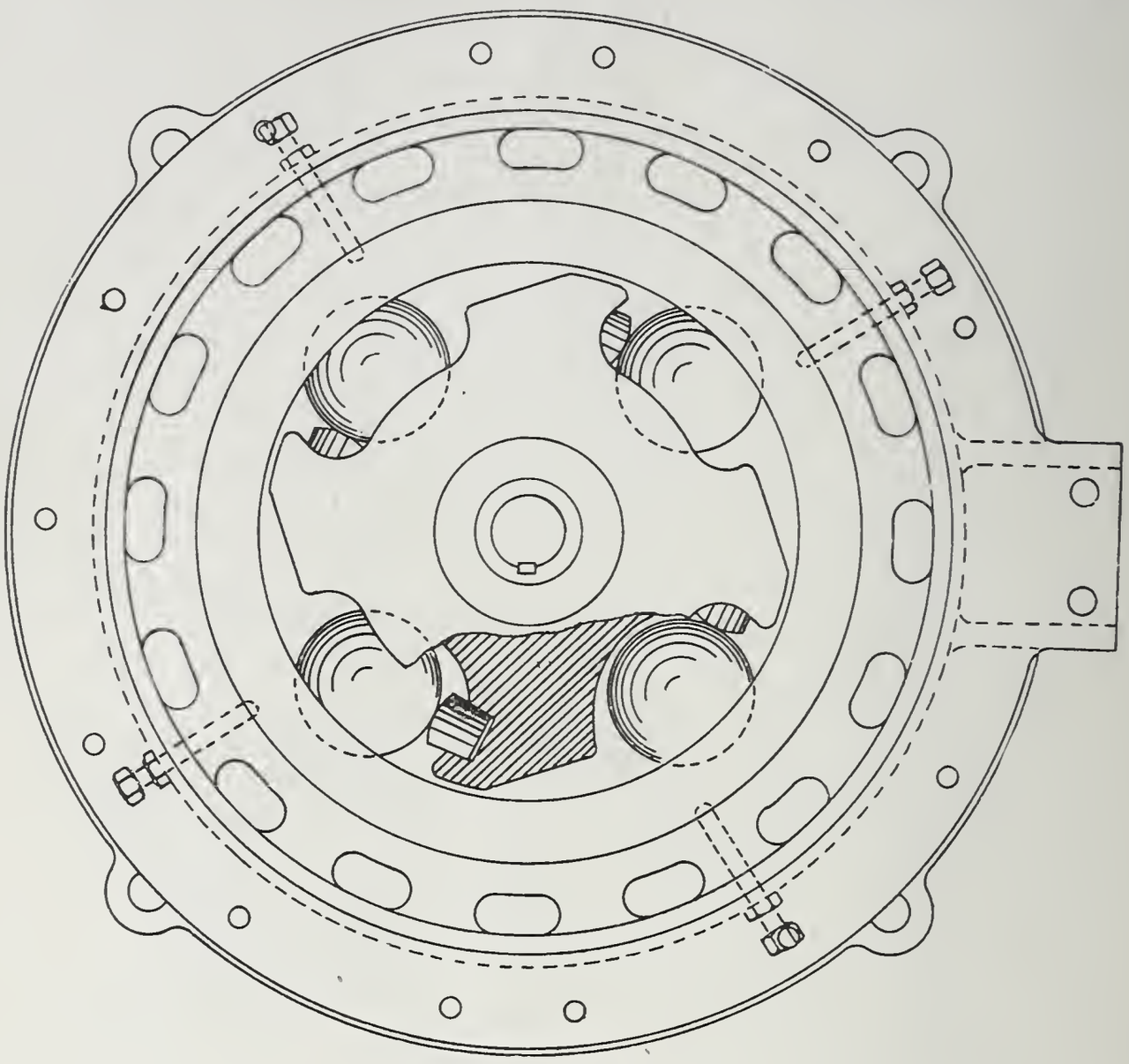

Fig. V.

present day are more or less deficient in these requirements. This circumstance has also led me to take part in the efforts that have been made to solve the problem. My researches have culminated in the construction of the "Morel Ball Pulverizer," as shown in Figs. IV. and V. The principle of this mill is one in which the grinding is accomplished partly by per-

cussion and partly by pressure. The principal part is a large steel ring, having a concavity in its inner side, in which spherical balls are made to fit closely. These balls, nine inches in diameter, are four in number and made of solid forged steel; they are located between the arms of a driving armature, also made of

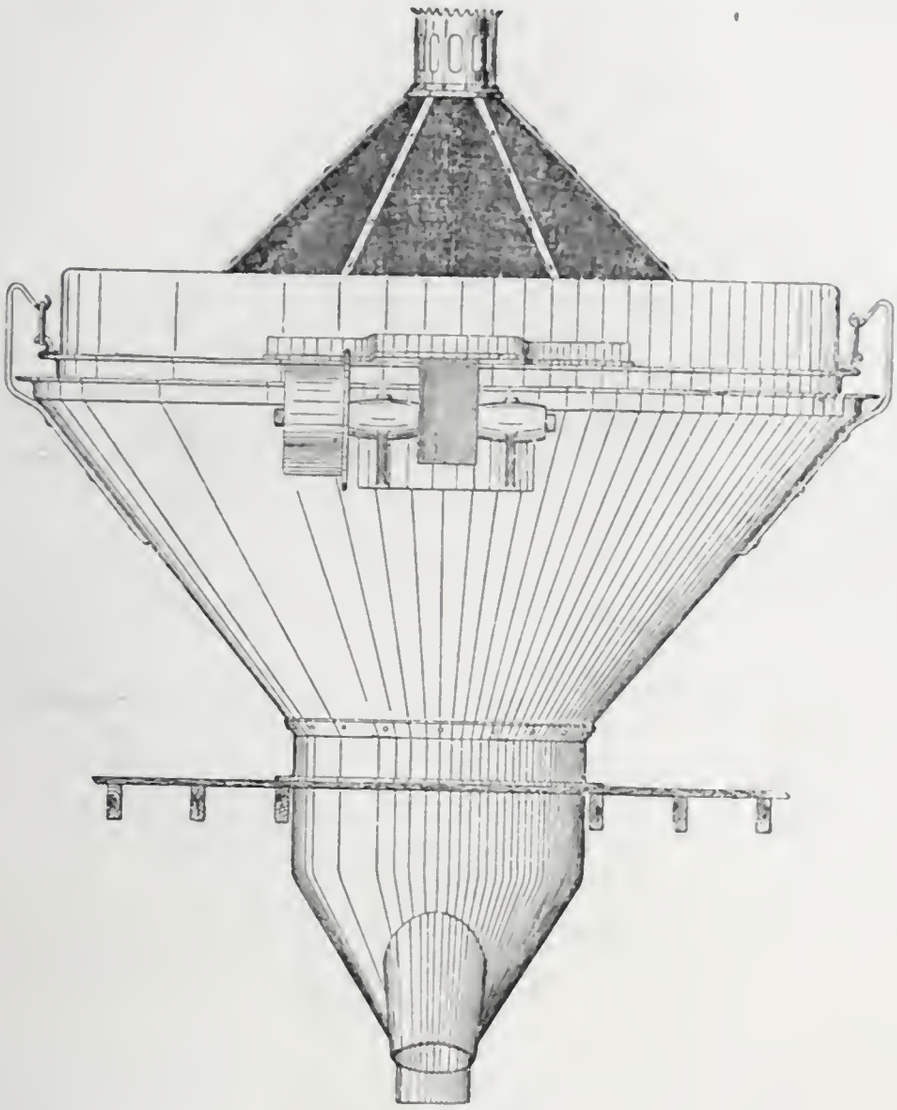

Fig. VI.

steel, and set on the vertical shaft placed in the center of the mill. A circular screen is placed over the ring, allowing the finely ground material to pass through the holes and returning the coarse parts under the balls. The material is introduced in the center from an automatic feeder located on the mill itself. The pulverizer complete weighs over nine tons, of which nearly 5,000 pounds are specially treated steel. It is, I believe, the largest grinding machine ever built.

The mill is run at a speed of about 250 revolutions a minute. When running, the balls have two motions, one around and the other on themselves. The grinding is done under the high

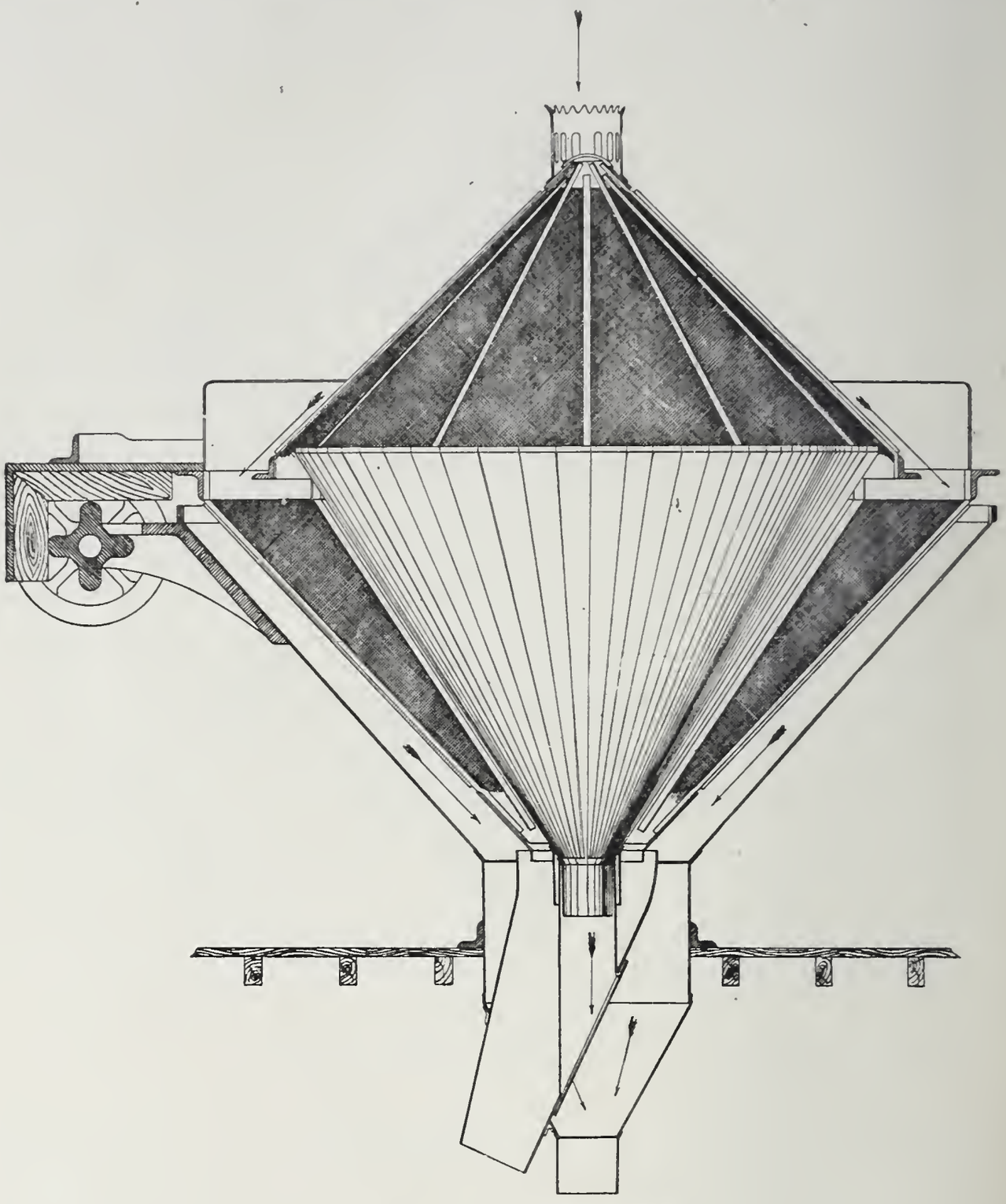

Fig. VII

pressure produced against the ring by the centrifugal force of the balls. While the machine is in operation a slight air current is created, strong enough to carry out the ground material, in the form of a dense cloud, through the screen and holes of the casing.

The temperature of the mill is kept low by the air current set up. The wearing parts are the ring and balls, and they wear without losing their shape. The mill can be run 24 hours a day and continuously for several weeks. It is only necessary to stop to replace the steel plugs of the driving armature.

I have had the best opportunity to test the merits of this process of grinding, and after a long and varied experience under all sorts of conditions, the last difficulty has been confined to the use of the proper quality of steel in making the working parts. The high-grade steel now manufactured in the United States has fortunately supplied the means of overcoming this final trouble.

The preparation of the finished product does not end with the millstone or the pulverizer. To regulate the fineness of the product, it is necessary to pass it through screens. The best practice is not to attempt to get a finished product from the mill. It is preferable to relieve the mill from all the work that can be performed with greater economy at another stage of the process. The use of revolving cylindrical screens is fast disappearing. Several new devices have lately been produced, and some of them can be recommended. Among them I do not see anything better than the double conical screen represented in Figs. VI. and VII. With this method of screening a very strong wirecloth can be made to do the work of a much finer mesh, and is, of course, much more durable.

DISCUSSION.

Mr. R. W. Lesley.—Much that is contained in Mr. Giron's paper on the grinding of cement is well known to the trade, and possibly some criticism might be directed to the class of crushers recommended by him. On a good deal of cement material the Gates Crusher gives better results than the Blake Crusher he suggests. With reference to the Morel Mill, my information is that the cost of repairs is very great, and that the power required is also considerable. The matter of repairs, however, may have been overcome by the use of a stronger steel, as outlined by Mr. Giron. Few of these mills are in use in this country.

In connection with Mr. Giron's treatment of the subject of

cement, I will call attention to the fact that in my reply to that gentleman, in the matter of the burning of Portland cement, published in the Proceedings for July, the advantage of the old process over the rotary process is stated to be about "60 per cent." per ton of manufactured cement. This is a misprint, and should have been "sixty (60) cents."*

In this connection, attention is called to two other matters in Mr. Giron's closure to my reply to his paper. In commenting upon my statement as to the difference between the specific gravity and density of the two materials used in making rotary kiln cement at the works I referred to, Mr. Giron states that "the difference in specific gravity, etc., between these two raw materials is hardly measurable," thus denying a statement made by a fellow-member in a matter of scientific precision without giving a figure, calculation, or authority. In order that the thing may be put in a scientific aspect, the writer would say that the figures given by him as to these two elements were made by the chemist who did the analyzing for the works referred to, while they were under Mr. Giron's charge, and who, until a very recent period, was so employed. These figures are as follows:

	Specific Gravity.	Density.
Limestone,	2.96	2.7
Cement rock,	2.59	2.3

In another part of his closure Mr. Giron says that "the capacity of works running under the rotary kiln process is already about as large as the capacity of those works running under the old process." During the year 1893, there were running thirteen Portland cement works, producing Portland cement in the old way, and four (4) producing cement by the rotary process. The old process works were located as follows:

Lehigh District, Pa.,	5
Wampun, Pa.,	1
New York State District,	3
Indiana,	1
South Dakota,	1
California,	1
Texas,	1

* See errata slip.

According to Trade Reports made to Mr. Cummings, of Hartford, Conn.; Census Reports made to Prof. Newberry, of Cornell University, and Railroad Statistics made to the N. Y. Central R. R. of New Jersey, Lehigh Valley, West Shore, Erie, Lake Shore, Pennsylvania and Chicago, Milwaukee and St. Paul Railroads, one single concern manufacturing under the old process, produced in 1893 nearly twice as much Portland cement clinker from its kilns as all the works producing rotary kiln cement put out during the same period. In point of actual capacity this single one, out of thirteen works producing cement in the old way, has a greater capacity than all the rotary kiln cement works running in 1893. These facts I stand ready to prove.

Mr. Pierre Giron.—I am glad that the unusual privilege of answering an author's closure has been granted to Mr. Lesley, who is thus in a position to formulate every possible objection he may have against the rotary kiln. Among the many statements to be found in my closure, and emphasizing what I had already demonstrated in my paper, concerning the superiority of the rotary kiln, as regards the quality of the product, the saving in labor and the cost of fuel, Mr. Lesley takes exception to two only—the specific gravity of a particular rock and the quantity of cement manufactured under the old and the new processes. These two points are really the least important, and as they do not affect the main subject of my paper, I might well afford to leave them unanswered were it not that I wish to leave no doubt of the accuracy of any of my statements.

The figures given by Mr. Lesley on the specific gravity of the Coplay cement rock are devoid of meaning, because they are incomplete. The analysis of the samples should be given; also, to be precise, the nature of the rock. Both of these materials belong to the same geological formation, and are to be found in such variety as to make it impossible to classify them otherwise than by chemical analysis. Even in the same quarry it is not uncommon to find the most extreme variations, and in these exceptional cases it is quite possible that the great difference in chemical composition might cause some irregularities in the specific gravity. But it would be a gross error to admit that these various rocks cannot be brought to uniformity by a thorough

process of grinding and mixing, and this is the point. My long experience in the handling of such materials enables me to say that there is no difficulty in getting perfect results with the rotary kiln under these conditions.

In regard to the capacity of the works running under the old process, compared to the capacity of the works running under the new process, my statement was based on the number of kilns in each case. There are now in the United States twenty rotary kilns:

New York,	6
New Jersey,	3
Pennsylvania,	4
Ohio,	6
California,	1

The number of common kilns in the old process works, enumerated by Mr. Lesley, does not exceed 150. None of the statistical documents to which I am referred could tell me what is being actually done in the widely scattered districts where the cement industry is carried on. Accurate and precise information on that score will be available only later on. As it is impossible to know at present the actual production, my estimates can only be based on the *kiln capacity* of all these cement works, and 20 rotary kilns are certainly capable of turning out at least as much cement as 150 common kilns, this fact would lose none of its significance even if it were proved that the production had been less for the rotary kiln, as it cannot be expected that a new process just in its period of development should attain at once its full capacity.

XV.

A BRIEF REVIEW OF THE EXHIBIT OF THE BETHLEHEM IRON COMPANY AT THE WORLD'S FAIR.

By Lieutenant William H. Jacques, Visitor.

Read October 7, 1893.

If I can atone in any way for America's very inadequate representation of her steel productions by a recitation of what the Bethlehem Iron Company sent to the World's Columbian Exposition, I shall feel I have done a service to our profession. But I shall make no attempt to compare the Bethlehem Exhibit with that of Mr. Krupp, which is a veritable Exposition in itself, but shall present it only as showing the latest and highest development of the class of objects it covers.

On entering the Transportation Building, even those unacquainted with the products of iron works, are attracted to the gigantic structure that strides the main aisle, like the Colossus of Rhodes. This is an exact reproduction of Bethlehem's 125-ton steam hammer—the largest in the world—under which the heaviest armor plates are finished and shaped. It towers, ninety-one feet in height, to the very roof beams and so excellently have the wood and staff been moulded together, that to all appearances the model is solid iron. The anvil-block could not be shown in place, as it would obstruct the passageway.

As a description of this hammer may be of interest, I present some details prepared for Mr. Swank for the last edition of his "Iron in All Ages." Although since the completion of the Parks Brothers' 17-ton hammer, two others of moderate proportions have been erected, viz., the 20-ton hammer of the Latrobe Steel Works, and the Midvale hammer of 30 tons, both employing top steam to increase their forging power, it has been left for the Bethlehem Company to add to its already splendidly equipped plant the largest and most efficient hammer in the world—a single-acting instrument of 125 tons. The building in which this hammer has been erected is 500 feet long, and is located

on ground that was partly an island and partly the bed of the southern channel of the Lehigh River, turned from its course to provide the hammer site.

A pit 80 feet square was excavated below the water level and piles were thickly driven, both for the anvil foundation and hammer frames. The stone walls for supporting the latter have a depth of 30 feet, separated from the anvil foundation lest any sinking of this latter should affect the framework of the structure itself.

The hammer rises to a height of 90 feet from the floor line. The housings proper are each composed of two parts, the lower ones weighing 71 tons each, the upper ones 48 tons each. These are bolted together and surmounted by an entablature of 61 tons carrying a cylinder of 76 inches in diameter by 24 feet high. The housings are clamped to base plates, each 10 feet by 8 feet and weighing 56 tons, giving a 42 feet longitudinal width of frame and a working floor width inside of housing of 22 feet. A 16-inch steel piston-rod 40 feet long actuates the enormous tup, which is composed of three parts, two forming the ram, a third the die. The hammer is single-acting, steam-lifting only, the total weight of falling parts, length of stroke and gravity governing the work done.

The anvil foundation consists of piles driven to bed rock or gravel, timber frames, cork and shavings cushion, steel slabs and 22 iron blocks carefully machined and fitted, forming a metal mass of 1,800 tons, arranged in the form of a pyramid. To secure an even floor for working, the spaces between the frame and anvil foundations are closed with cribbing, leaving exposed only the anvil block. The specially designed valve gears have worked most satisfactorily, one man easily controlling the motions with one hand.

The hammer is served by four heating furnaces conveniently placed and by four gigantic cranes, each of 300 tons capacity, having longitudinal, transverse, vertical and turning motions, by which every position and movement of the forgings can be easily controlled.

In describing this hammer as one of 125 tons, it is meant that the weight of tup (including die), piston and rod is 125 tons,

which falling a distance of 16½ feet (full stroke) without top steam produces the full power of the hammer.

THE PRINCIPAL POWERFUL STEAM HAMMERS IN THE WORLD ARE:

COMPANY.	TOWN.	COUNTRY.	TYPE.	WEIGHT IN TONS.
Sir Wm. G. Armstrong, Mitchell & Co., Limited	Elswick, Newcastle-on-Tyne	England	Top-steam	35
British Government	Woolwich	England	Top-steam	35
Kama Steel Works	Perm	Russia	Single-acting	50
Aboukoff Steel Works	Aboukoff	Russia	Top-steam	50
Cast Steel Works of Fried. Krupp	Essen	Rhenish-Prussia	Single-acting	50
St. Chamond Steel Works	St. Chamond	France	Single-acting	80
Schneider & Co.	Le Creusot	France	Single-acting	100
Marrel Brothers	Rive-de-Gier	France	Single-acting	100
Terni Steel Works	Terni	Italy	Single-acting	100
The Bethlehem Iron Co.	South Bethlehem, Pa	United States	Single-acting	125

In describing these hammers, the *weight* given is the sum of the moving parts, *i. e.*, piston, piston-rod, tup and die. The column headed *type* indicates whether top-steam is employed or not.

Begun in 1889, the Bethlehem hammer was successfully put in operation June 30, 1891, since which time many huge forgings for armor plates and other war and structural material have been shaped under it.

The exhibit proper was divided into three sections. In the first were two immense steel forgings for the tube or barrel and jacket of a Navy 13-inch B. L. Rifle, weighing respectively 26.3 tons and 25.4 tons—examples of hydraulic forged hollow steel forgings. Here was also the nickel-steel ventilator armor for the monitor "Puritan," 7 feet in diameter, 6 inches thick, weighing 9.1 tons, forged in one piece without welds. A feature of this section was a Navy 12-inch B. L. Rifle, fabricated at the Washington Navy Yard of Bethlehem's fluid-compressed, hydraulic forged steel. It weighed 45.2 tons, was 37 feet long, had a muzzle velocity of 2,000 feet seconds, and fired an 850-pound projectile with 425 pounds of powder with an energy sufficient to perforate 22½ inches of iron. Its outside diameter was 3 feet 9 inches.

In the second section was a model of a 113-ton steel armor plate ingot and a pile of forged steel hoops, with which were three splendid examples of steel armor. The largest was a curved 17-inch nickel steel plate, 12 feet 1 inch long, and 8 feet 4 inches wide, weighing 31.2 tons—one of thirteen required to form a

barbette of the battleship "Indiana." The armor required for this battle-ship was:—

Kind.	No. of Plates.	Thickness.	Weight, Tons.
Diagonal	10	14	245
Side	20	18	650
Barbettes for 13 ″ B. L. R.	26	17	810
" " 8 ″ B. L. R.	8	8	115
" " 4 ″ B. L. R.	4	6	43
		Total	1863

The next was a case-hardened nickel-steel plate, $10\frac{1}{2}$ inches thick, 8 feet long, 10 feet wide, weighing 9.3 tons, which was subjected to an attack of the enormous energy of 25,040 foot tons, during which the five 8-inch, 250 pounds Holtzer armor-piercing shells lost their identity and were completely pulverized, without seriously injuring the plate. The third plate was the first heavy steel armor plate made in the United States. It was $11\frac{1}{2}$ inches thick, 6 feet long, 4 feet 6 inches wide, and was tested in 1891. It weighed 5.7 tons. In this section was one of the most remarkable articles of the exhibit—a fluid-compressed steel ingot 15 feet long, 54 inches in diameter, weighing 48.3 tons. From a similar ingot weighing 65 tons, the axle of the famous Ferris wheel was made. The third section contained a hollow hydraulic-forged shaft 67 feet long and 20 inches in diameter, weighing 24.6 tons, with an internal diameter of $8\frac{1}{4}$ inches, forged in one piece; together with the paddle-shaft for the Old Colony Steamer "Puritan," 39 feet 5 inches long, 2 feet 3 inches in diameter, having a 9-inch hole, and weighing 39.4 tons; and the crank-shaft for the U. S. Cruiser "Minneapolis," 9 feet $7\frac{5}{8}$ inches long, $16\frac{1}{8}$ inches in diameter, having a $7\frac{1}{2}$-inch hole and weighing 4 tons. Both of these were finished.

Accompanying these were a smooth forged trunnion hoop for a 12-inch Armor Gun, Whitehead torpedo, air flasks, air cushions, cylinders, sections of rails, specimens of nickel steel, etc.

XVI.

VISIT TO PHILADELPHIA OF MEMBERS OF LA SOCIÉTÉ DES INGÉNIEURS CIVILS DE FRANCE.

September 26th to 28th, 1893.

By John C. Trautwine, Jr., Active Member of the Club.

Read October 7, 1893.

In the spring of 1893, our Club received from the General Committee of Engineering Societies in Chicago, a notification that a body of some fifty visiting members of "La Société des Ingénieurs Civils de France" might be expected to visit Philadelphia in connection with their visit to the World's Fair. This communication submitted that it was desirable that the Club should take measures for the reception of these gentlemen, and for their entertainment while in Philadelphia.

A committee was accordingly appointed, at the Business Meeting of June 3d, to consider the matter. This committee met on June 23d and appointed a sub-committee of three, with power to act, composed of Messrs. John C. Trautwine, Jr., chairman, Edward K. Landis and Henrick V. Loss. This sub-committee proceeded to frame a programme, and to make the necessary arrangements for carrying it into effect.

The visiting party, with Mr. Louis Rey as chairman, arrived in New York on September 3d, and its members were very handsomely entertained there for several days, as guests of the combined engineering fraternity of the United States, and especially of those whose good fortune it was to enjoy the hospitalities extended by the "Société" to those American engineers who visited Paris in 1889.

From New York, the party proceeded via Niagara Falls to Chicago, and, after spending about ten days in visiting the World's Fair, returned eastward, visiting St. Louis, Pittsburgh and Washington en route.

On Monday evening, September 25th, the members of the sub-committee proceeded to Washington and met the Marquis

De Chasseloup-Laubat, as representative of the party, at the Ebbitt House. The next morning they returned to Philadelphia with the French engineers on the special Pullman train which conveyd them from Pittsburgh to Jersey City, and which was placed at their disposal by the Pennsylvania Railroad Company.

Arriving at the Broad Street Station, the party was met by our President and several of our members, accompanied by Mr. Louis Vossion, the French Consul, Mr. William H. Brown, Chief Engineer of the Pennsylvania Railroad, Mr. Joseph T. Richards, Engineer of Maintenance of Way, and Mr. William L. Ziegler, Engineer of Construction. Mr. C. C. Schneider, of Pencoyd Iron Works, contractors for the Broad Street Station train-shed roof, Professor Steiner, of Germany, and Mr. Jules Viennot, were also present. After inspecting the new and still unfinished train-shed, the party proceeded to the City Hall, where, after viewing the statue of William Penn and the spiral staircases in the corner towers, they proceeded to the office of his Honor the Mayor, who cordially welcomed them to the City. The Mayor's remarks were responded to by Mr. Louis Rey, the chairman of the party, and the visitors then proceeded, under the lead of four guides, provided by Mr. William C. McPherson, Superintendent of the City Hall, to examine the heating and ventilating plant, the Electrical Bureau, the rooms of the Supreme Court of Pennsylvania, the model of the Centennial Exhibition and other prominent features of the building.

Superintendent McPherson had kindly arranged to have the tower elevator running, and the party was thus given a fine bird's-eye view of the City, and an opportunity to examine so much of the iron superstructure of the tower as is now in place. In this they were assisted by Mr. John Ord, the architect of the building, Mr. Francis Schumann, President of the Tacony Iron & Metal Company, contractors for the work, and Mr. C. R. Grimm, its designer. By the courtesy of Mr. George S. Webster, Chief of the Bureau of Surveys, and Member of the Club, maps of the City were spread out upon the platform of the tower, and greatly facilitated the orientation of our guests.

The party then passed through Wanamaker's Grand Depot and proceeded to the new Terminal Station of the Philadelphia

& Reading Railroad, at Twelfth and Market Streets, where they were met by Mr. Edwin F. Smith, Engineer in Charge and Member of the Club, and by members of the firm of Wilson Bros. & Co., engineers and contractors for the building. Under the guidance of these gentlemen the various features of the structure were studied.

A visit was then made to Independence Hall, where the party was addressed by Hon. Charles Emory Smith, Editor of *The (Philadelphia) Press* and Ex-Minister to Russia. Mr. Smith's remarks were responded to by M. Jules Pillet, in the absence of the acting president.

In the evening a reception was held at the Club House, the rooms of which were handsomely decorated with the French and American colors. Invitations had been sent to all of the members of the Club, and to about two hundred and fifty other persons. Nearly two hundred gentlemen were present, and an informal supper was served.

The next morning, Wednesday, September 27th, the party visited the ship-yards of the William Cramp & Sons Ship and Engine Building Co., at Port Richmond, proceeding thither by a special train furnished by the courtesy of the Philadelphia and Reading Railroad Company. The train left the new Terminal Station at Twelfth and Market Streets at 9.15 A.M., and, proceeding via Falls of Schuylkill and Nicetown, reached its destination about 10 A.M. The party was cordially received by the officers of the Company, and spent several hours in the inspection of the works, including the discussion of a very enjoyable lunch, served by the courtesy of the proprietors. Among the objects of special interest examined here were the three sets of double turbines, of 5,000 effective horse-power each, for the Niagara Falls Power Co.

At 3 P.M. the party went on board the police boat "William S. Stokley," placed at their disposal by the courtesy of his Honor the Mayor, and were favored by a display of the fire-fighting capabilities of the new fire-boat, "Edwin S. Stuart." After this, the "Stokley" proceeded first upstream to the head of Petty's Island, then down to Greenwich Point, and finally back to Walnut Street Wharf, whence the party proceeded in carriages

to their lodgings at the Continental Hotel. On the river trip Messrs. L. Y. Schermerhorn, Member of the Club and President of the American Dredging Company, and Mr. Charles Truesdell of the United States Engineer Office, accompanied the party and explained the government work for the improvement of the harbor. In the evening an informal conversazione was held at the Club House.

The next morning, Thursday, September 28th, the party divided into several sections. One group, of about fifteen persons in all, proceeded via the Pennsylvania Railroad to Reading, Pa., under the leadership of Mr. Loss and accompanied by Mr. Jules Viennot, who in many ways rendered signal service to the Committee throughout its labors. A special car on the 8.35 A.M. train from Broad Street Station had been placed at their disposal by the Railroad Company, and the time passed so agreeably that when our visitors arrived at the Carpenter Steel Works, they could scarcely believe that they had reached their destination. They were very cordially received by Mr. J. H. Carpenter, General Manager, who conducted them through the Company's establishment, where they viewed with great interest the manufacture of armor-piercing projectiles, of which this Company makes a specialty. After this a very excellent dinner was served at the Wyomissing Club by courtesy of Mr. Carpenter, who then escorted the party by the Gravity Railroad to the summit of Mount Penn, where the visitors were entranced by the glorious view of the City and the Schuylkill Valley which unrolled itself before them. This party returned to the City in their special car on the train leaving Reading at 4 P.M.

Of those who remained in Philadelphia, the major portion spent the morning in very interesting visits to the Baldwin Locomotive Works and the shops of Messrs. William Sellers & Co., Incorporated, and in the afternoon proceeded in omnibuses from the Continental Hotel, via Girard College, where a very brief stop was made, to the Fairmount and Spring Garden Water Works, where they were met by Mr. John L. Ogden, Chief of the Water Bureau, Mr. F. L. Hand, Superintendent, and Mr. Emile Geyelin, the designer of the turbines at the Fairmount Works. From the Spring Garden Works the party proceeded via the site of the Centennial Exhibition, Belmont Mansion, City Avenue

Bridge, Wissahickon Drive and School Lane, to the Chelten Avenue Station, Germantown. Upon their arrival there, a special train of three cars, placed at their disposal by the Pennsylvania Railroad Company, was ordered down from Chestnut Hill, and, arriving in about ten minutes, carried the party swiftly and without a stop to Broad Street Station, in about twelve minutes more.

The two parties, together with a number of our guests who had made independent visits during the day, assembled at the Manufacturers' Club, where a dining-room had been kindly placed at their disposal, and where dinner was served at 6 P.M.

Among those present, besides our guests of the French Society, the President of the Club, members of the Board of Directors, and members of the Reception Committee, were Mr. Louis Vossion, French Consul, Mr. J. H. Carpenter, Mr. Jules Viennot Mr. Edwin S. Cramp, Mr. Walter Wood, Mr. Washington Jones and Mr. William C. Williamson.

After the dinner, Mr. Birkinbine expressed for the Club its pleasure at having the visit of these distinguished strangers, and its regret that their stay with us had been so short and was so soon to close. Mr. Rey responded in his native language on behalf of the guests, expressing the gratification which their visit had afforded them. Mr. Trautwine, Chairman of the Executive Committee, thanked the French engineers for the opportunity which their visit had given us of expressing our appreciation of the courtesies extended to our brethren in Paris in 1889, and begged that Philadelphia might retain its place in their recollections of their American trip.

The Marquis De Chasseloup-Laubat and Mr. Vossion, the French Consul, made brief remarks appropriate to the occasion, and the party adjourned to Broad Street Station, where the special train was in readiness to convey them to New York. The train left shortly after 8 o'clock, the visitors crowding the platforms of the cars and leaning from the windows, where they waved their hats and shouted "Vive les États Unis."

It is believed that the Club may congratulate itself upon having made the visit of these eminent French engineers a source of real satisfaction to them, as it certainly was to all those of our members who participated in it.

WILLIAM W. THAYER.

William Watmough Thayer, late Active Member of this Club, son of President Judge M. Russell Thayer, of Philadelphia, was born at Chestnut Hill, in the County of Philadelphia, July 11, 1862. He received his primary education from private tutors and at the Episcopal Academy in Philadelphia. From there he passed to the University of Pennsylvania, entering the Class which graduated in 1882. Subsequently he was entered as a law student at the University, but after a brief experience abandoned the study of the law for the profession of a Civil Engineer—a profession for which his natural tastes and his fondness for and proficiency in mathematics afterwards proved that he possessed a peculiar adaptability. He pursued his engineering studies in the office of his elder brother, General Russell Thayer, who was then engaged in the profession of a Civil Engineer in the city of Philadelphia; being at the time also Chief Engineer and Superintendent of Fairmount Park. He remained in General Thayer's office until 1883, when he joined the staff of the Assistant Chief Engineer of the Philadelphia & Reading Railroad Company, in which service he remained about three years, being engaged in a great variety of work, especially on the Narrow Gauge Road between Philadelphia and Atlantic City. During a part of this period he was engaged in the inspection of mines, but much the larger part of his time was spent upon work in the field with the various location and construction corps. In 1885 and 1886 he was Assistant Inspector of Bridges and Track Material in the Pennsylvania Railroad Company. Leaving the Pennsylvania Railroad in 1886, he accepted the position of Assistant Engineer in the Baltimore & Ohio Railroad Company.

While in this service his principal work was superintending the building of the Twenty-fifth Street tunnel in Philadelphia, on the line of the connecting road between the Baltimore & Ohio and the Philadelphia & Reading Roads. An interesting account of this work is contained in a paper of his read before the

American Society of Civil Engineers at its annual meeting at Fortress Monroe, in June, 1892.

After the completion of the Twenty-fifth Street tunnel in 1887, Mr. Thayer accepted the position of Assistant Engineer of Fairmount Park.

On the 15th of December, 1889, he was appointed Surveyor and Regulator of the Fourth Survey District of Philadelphia, in which employment he continued until his untimely death on the 14th of March, 1893. During the period in which he held this position, he accomplished a large amount of work in all the various branches relating to municipal engineering; being also an Active Member of the Philadelphia Board of Surveyors. In the last days of his life the surveys connected with the construction of the Reading Terminal Road engaged a large portion of his attention. But among all these various works none interested him more than the survey for the proposed Park Boulevard projected from the City Hall to Fairmount Park. Upon this work he expended a great deal of time and labor. Mr. Thayer, in addition to being an Active Member of "The Engineers' Club of Philadelphia," was also an Associate Member of "The American Society of Civil Engineers."

He had for some years past suffered from an organic weakness of the heart, which, being greatly aggravated by an attack of influenza, proved fatal. He died, after a short illness, at his father's residence in Philadelphia (which was his home), on the morning of Tuesday, the 14th of March, 1893, being then only in his thirty-first year.

Thus suddenly and prematurely ended a career which gave the brightest promise of future usefulness and of distinction in his profession.

Mr. Thayer possessed many attractive qualities and accomplishments. Not only was he an able mathematician and engineer, but he possessed also social characteristics which had a great fascination for all who came within the sphere of their influence. His conversation was sprightly and animated; radiant always with a sincerity which immediately enlisted the attention of his hearers.

NOTES AND COMMUNICATIONS.

PROMINENT FEATURES OF THE WORLD'S COLUMBIAN EXPOSITION.

Contributed by JOHN BIRKINBINE, *at Meetings of October* 7 and 21, 1893.

IN presenting descriptions and lantern slides of some prominent features of the World's Columbian Exposition, the purpose has been to notice points presumably of special interest to engineers, in the hope that this may encourage other members to record details of other exhibits which impressed them individually. No claim is made for original research, nor even for critical review; nor was such attempted. The notes offered were merely to invite attention to a few of many important displays which attracted the attention of an engineer, and prominence given to exhibits must be considered solely as a personal selection of topics to which attention is invited.

Visitors to the World's Fair, at Chicago, were impressed with the poverty of the metallurgical exhibit of the great iron and steel works of the United States, and the general unfavorable comparison, with but few exceptions, which they made with some of the impressive German and Swedish exhibits. Several reasons may be assigned for the failure to properly display the development of the iron and steel industry of the United States, but briefly the responsibility may be shared by the various American iron and steel companies, and by the management of the World's Columbian Exposition.

The renowned WORKS OF FRIED. KRUPP, at Essen on Ruhr, in Rhenish Prussia occupied a separate pavilion on the lake shore, an iron building constructed by the Gutehoffnungshütte of Oberhausen, ornamented with sculptures and stucco, and provided with machinery, boilers, a draft stack, etc. This building had a main hall 60 meters by 25 meters by 13 meters, approximately 197 feet long, 82 feet wide and 43 feet high, and an annex or entrance hall 42 meters by 7.5 meters by 9 meters, approximately 138 feet long, 24.5 feet wide, and 29.5 feet high. The building was entirely occupied by exhibits of guns, gun carriages, projectiles, armor plate forgings, moulded steel castings, pressed and forged steel articles, etc., produced and fabricated in the Krupp works.

In addition to the exhibits in the pavilion, Krupp had a coast gun 42 c.m. bore (16.54 inches), and a length of 33 calibres (45.93 feet), mounted on a Pennsylvania Railway truck, having been handled to this from the vessel by the new crane of the Maryland Steel Co.; for this gun, with breech closure, weighed 120.46 tons. It carried a charged projectile weighing from 2,200 to 2,500 pounds, which, when driven by 900 pounds of brown powder, was claimed to be able to penetrate at 2,200 yards a wrought-iron plate three feet thick if placed at right angles.

In the pavilion were a number of large cannon, although small in comparison with the one just described. Among these (reduced to American equivalents) was a 12-inch gun with a barrel 35 feet long, mounted on a hydraulic ship carriage; the gun weighed 61.5 tons, the carriage 53 tons, and the shield 12 tons. With 227 pounds of

smokeless powder, or 430 pounds of brown powder, a projectile weighing 1,000 pounds was claimed to pierce at right angles wrought-iron plates from 32.5 to 38 inches, and steel plates 21.5 to 25 inches thick at 2,200 yards.

Other interesting exhibits were coast guns—one 11 inches in diameter and 37 feet long, and one 9.45 inches in diameter and 31.5 feet long, mounted on a center-pivot carriage, and arranged so as to be elevated 45°; this was claimed to have the longest range of any gun throwing a projectile of equal weight, viz., from 353 to 474 pounds, with 93 pounds of smokeless powder or 254 pounds of brown powder. A shot was fired from this gun in 1892, in the presence of the Emperor of Germany, and the range, when measured, was found to have covered 22,120 yards (over 12 miles). The trajectory of this shot has been graphically shown in its approximate relation to Mount Blanc, and the statement made that if fired at Pré St. Didier, in the Alps, at an elevation of 3,280 feet above the sea, it would cross 9,000 feet above the summit of Mount Blanc (which is nearly 16,000 feet above sea level), and land over 12 miles from the mouth of the gun near Chamounix.

Various ship, coast, siege and field guns, ranging in size from the large ones described to mountain and bush guns to be carried on mule-back, were exhibited, also projectiles and armor plates into which the latter had been forced.

Among the examples of rolled metal was a plate of ingot iron for a hydraulic bending press, which was 27 feet long, 10¼ feet wide and 1 foot thick, weighing 61½ tons; a steel boiler plate 65.5 long, 10 feet 10 inches wide and 1¼ inches thick, weighing 16 tons; and a steel boiler head 12¾ feet in diameter and 1½ inches thick, weighing 3⅓ tons.

Among the forgings may be mentioned a hollow shaft, forged by hydraulic power from a block of crucible steel, 49 inches in diameter and 8.8 feet long. This shaft was 12 inches in diameter, had a length of 82 feet, and was bored out longitudinally to a diameter of 4⅓ inches on a lathe with a bed 111½ feet long. The weight was nearly 12 tons. There were also three sections of steamship shafts, the weight aggregating over 103 tons, and the length 90 feet 3 inches, made from Martin steel.

Some remarkable castings were also shown. For instance, a molded steel sternpost for an armored vessel weighing 12.6 tons, and the companion rudder-frame weighing 11⅛ tons. The large size of these two articles, the latter of which required a space of 26 feet by 11½ feet, made transport by rail impossible, and they were therefore carried by teams to the Rhine, and thence by water to Chicago. There was also a screw propellor having a total weight of 26 tons.

Among the miscellaneous exhibits was a pair of portable tubular hoisting shears, stationed over the 12-inch gun, and capable of lifting 83.65 tons.

The chimney belonging to the pavilion is also worthy of special mention, being 88½ feet high, with an interior diameter of 3 feet, built of shaped brick with vertical perforations, the bricks being capable of bearing a pressure of over 5,000 pounds per square inch. It was claimed that these perforations increased the adhesion to 61½ pounds per square inch as against but 21¾ pounds in solid brick, thus insuring stability.

The pavilion was also equipped with machinery to furnish power for handling the large guns.

(A series of lantern slides clearly illustrated the description.)

The Intramural Railway was the popular transportation facility provided within the World's Fair enclosure. It was an elevated structure, 3.6 miles long, formed of pine posts (ranging in height from sixteen to thirty-five feet, according to the grades and obstacles to be overcome), resting upon concrete foundations and tied at the tops by pine beams. The posts were spaced about twenty-five feet apart, and connected longitudinally by 15-inch steel I-beams, located so that an I-beam was directly under each of the four rails of the track. Across the I-beams were the wooden ties or sleepers, and the sixty-pound rails upon which the cars traveled.

The grades ranged from one-half of one per cent. to two per cent., and the radii of the curves varied from 100 to 300 feet.

This construction is much cheaper than the ordinary iron elevated railway structure, such as is used in Chicago, costing about $500,000 per mile of double track, exclusive of franchises, rights of way, real estate, and equipment. Of this amount, the girders supporting the train cost about $60,000 per mile ; for these girders must be deep enough to sustain the weight of the engine when concentrated on a short wheel base; but with electric propulsion the weight can be distributed over the structure more evenly, and permits lighter girders being used.

In operating the Intramural Railway, electricity was applied to heavier work than had before been attempted in railway operation. The equipment was designed for a higher rate of speed than was employed on the road, the schedule being about fifteen miles per hour.

Twelve trains of four cars each were in constant service from 8 o'clock in the morning until 11 o'clock at night. The cars, each forty-six feet in length, had a seating capacity of ninety-six passengers.

The conductor which carried the electric current consisted of sixty pound T-rails, placed upon wooden insulators mounted upon porcelains, and set parallel with and outside of the traffic rails about twelve inches. The conductor rails were connected by sheet-copper plates to insure electrical joints. For the purpose of avoiding the use of feeders at the portion of track nearest the power-house, a double line of rails was used, and each rail connected together by means of large copper wires. At the ends most remote from the power-house a single line of rail was used, which gave the ordinary feeder system as it is used on overhead trolleys to-day. With the elevated structure, where teams or pedestrians cannot cross the tracks, it is possible to use the large conductors of either copper, iron, or steel, supported from suitable insulators on the structure above the track. It was found that the use of a steel conductor of sixty pound weight per yard gave ample carrying capacity and made a saving over the cost of copper.

The installation was one of direct transmission. The current collector performed the same office as the contact bar ordinarily placed on top of the surface electric railway cars, and was attached to the side of each truck on the motor car, overhanging about twelve inches, being thoroughly insulated from the truck and supporting a cast-iron shoe, which could be removed when worn out, and which by its own weight bore upon the steel conducting rail, thus making and insuring perfect contact.

The return circuit by which the current passed from the motor back to the generators was conducted through the wheels of the trucks to the track rails, and from the track rails to the steel eye-beams on which the structure was supported, the track rails being connected to the eye-beams by copper wires, the track rails only acting as a conductor during such time as the motor car is upon each set of rails.

The motors used on the trucks of the Intramural Railway were of the single reduction water-proof type, and had a rated capacity of 133 H. P. They were of the four-pole form, with but two field coils and two brushes. The armature was iron-clad, with the windings imbedded in the laminated iron core. As the weight of this motor, including the gear, was about 3800 pounds, the dead weight on a train was less than eight tons. A steam locomotive, to haul the same train, would weigh not less than twenty-eight tons. The motor was designed to give a speed of twenty-five miles per hour, and had sufficient capacity to take care of heavy passenger traffic such as is experienced on elevated roads where four, five and six cars are operated in one train. Each train was provided with one motor car, having four motors mounted upon two trucks, giving a total capacity of 500 H. P. per train. As the motor car carried passengers, their weight also was effective for traction purposes.

The motors were governed by a series-parallel controller, located on the front platform of the forward car, and this controller in turn was operated by air pressure. The operator had merely to turn a valve to admit and shut off the air supplied by an electric air pump, which had a capacity sufficient to supply the air brakes on the train as well as the pneumatic operating controller. The air pump started automatically when the pressure was below a certain point, and stopped automatically when the pressure reached a maximum.

Several illustrations exhibited the generating portion of the interior of the Intramural power-house.

There were ten boilers of the standard water tube type, of about 300 horse power, using oil for fuel. The power-plant consisted of five engines and five generators, of various sizes and types, ranging from 268 to 2,000 horse-power, of which the following is a general description.

(1) A McIntosh & Seymour tandem-compound engine, 13 by 23 by 22 inches, coupled direct to a 200 k. w. generator.

(2) A 2,000 horse-power cross-compound Reynolds Corliss Engine, 32 by 62 by 60 inches, from the E. P. Allis Co., having a 1,500 k. w. generator, mounted on its main shaft. This is not only the largest dynamo in the Exposition, but the General Electric Company state that it is the largest ever built. While its rated output is 1,500 k. w., or about 2,100 electrical horse-power, it could stand an overload up to 3,000 horse-power in an emergency. It was adapted to compound from 500 to 600 volts in going from no load to full load, and was adjustable for any intermediate range for compounding. Its total weight was 181,000 pounds, of which 73,600 pounds was in the revolving armature, 10 feet 6 inches in diameter, and 3 feet 3 inches broad. 80,000 pounds were in the field magnets, and 12,400 pounds in the commutators. The shaft on which the armature and the engine fly-wheel were mounted was two feet in diameter, and with the fly-wheel hub weighed 56 tons. The fly-wheel was 24 feet in diameter, and its weight about 85 tons, not far short of that of one of the four car trains run on the road. The rim velocity, with the engine making 80 revolutions, was about 6,000 feet per minute, and the energy stored in this revolving rim about equalled that required to accelerate four of the trains run on the road from a full stop to a speed of 30 miles per hour. The armature of the generator was built up of 17,200 pieces of sheet-iron punchings, with a total weight of 25 tons.

(3) A 1,250 horse-power compound engine, 22 by 34 by 36 inches, built by the

Lake Erie Engineering Company, and directly connected to a 750 k. w. generator. This engine made a record by handling the entire traffic of the road for weeks at a time without giving the least trouble. It moved 14 four-car trains alone, working at times under a load of 1,775 horse-power, or 42 per cent. in excess of its rated capacity. With the generator it occupied a space 13 by 24 feet, and stood 21 feet 8 inches high.

(4) A Reynolds Corliss tandem compound engine, 22 by 42 by 48 inches, of about 750 horse-power, coupled direct to a 500 k. w. multipolar generator.

(5) A Greene tandem compound engine, 20 by 38 by 48 inches, of 750 horse-power, belted to a 500 k. w. dynamo. It was the only engine in the station which did not follow the modern practice of mounting the dynamo on the engine shaft.

The Edison Tower of Light, erected by the General Electric Company, which was located in the center of the Electric Building, attracted by its size and brilliancy considerable attention. It was 85 feet high, surmounted by a bulb composed of over 10,000 pieces of cut glass, and brilliantly illuminated from the inside. The tower had about 6,500 incandescent lamps of from 5 to 32 candle-power in three colors, the controlling switches being placed in the base of the tower, permitting of numerous changes in illumination.

An Electric Derrick was also exhibited and used in installations. The magnetic hoist used in connection with it consisted of an iron-clad electro-magnet, capable of sustaining a weight of 2,000 pounds, the hoist being connected directly to the mast. The hoist itself consists of two side frames bolted to the mast, supporting two drums, with the usual cone clutches, ratchet pawls, brakes and an electric motor. A rheostat was provided for controlling the speed.

The Movable Sidewalk at the World's Fair was erected on the long steamboat pier running out into Lake Michigan, by the Multiple Speed and Traction Railway Company, and was a continuous movable platform 4300 feet long, the length of the pier, having a loop at either end and entrance and exit gates at convenient points along its length. The walk moves continuously in one direction and is divided into two longitudinal sections, one moving at the rate of three miles an hour and the other upon which seats are placed, at six miles an hour, so that the passenger steps from the stationary platform to the slower of the moving ones and from this to the faster, where he takes his seat and is carried as far as he wishes.

The track is elevated a few feet above the level of the pier and surrounded by a broad walk bounded by a railing. The movable platforms are covered by a roof supported by center posts. All the trucks are connected one with another by drawheads, and each section of platform has a thin sheet-iron extension projecting over the edge of the next, and wide enough to cover the spaces between when rounding the curves at the loops. A continuous moving floor is thus maintained. The trucks, of which there are 340, are 12 feet 6 inches long over all, and have a wheel base of 5 feet 9 inches. The gauge of the track is 45 inches, and the wheels (four to each truck) are of cast iron, with chilled treads 18 inches in diameter shrunk on light axles with journals $1\frac{7}{8}$ by 4 inches. The platform, carried by the projecting part of the frame, is 36 inches wide and of such a height as to just clear the stationary walk

over which it laps a few inches, and is provided with a strip of rubber tacked upon its edge.

The upper or six mile platform is composed of a series of trucks 12 feet 6 inches over all in length like the others, but boarded over their entire width, 5 feet 10 inches and upon this floor transverse seats are placed. This platform laps over the slower one, as the later does over the stationary walk.

The upper platform is carried upon two rails resting upon the tops of the wheels of the trucks. These rails, 4 inches deep and ½ inch thick, are simple flat bands of steel, flexible and endless. They consist of pieces welded into lengths of 130 feet each, which are riveted together by means of close-fitting machine-made joints. Fastened to the under side of the upper platform are brackets, in each of which is placed a block of rubber to serve as a spring, and bearing upon this is a shoe made of case-hardened steel, fitting loosely over the rail and sliding upon it as the cars enter and leave the curves. It was found that the expansion and contraction due to changes of temperature is only sufficient to cause a lateral movement of the rails over the treads of the wheels upon which they rest, of about one inch, so this has been provided for by having about 1½ inches play between the rails and the wheel flanges. The draw heads between the upper cars simply keep them properly spaced, for there is no tension upon them due to traction, as in the case of the lower trucks, and the upper platform moves as a unit at exactly twice the speed of the lower, as its speed is equal to that of the periphery of the wheels, while the speed of the trucks equals that of the axles.

The Electrical Equipment consists of general electric double reduction motors rated at 15 H. P. each, two of which are placed on each of the ten motor tracks. The trolley wire is strung on insulators under the platform at a level with the fixed rails on which the trucks run, and the arm extends downward from the overhanging of the slow platform, so that the trolley bears upon the upper, instead of the lower side of the wire. The current was rented from the Exposition Company and is generated in Machinery Hall. Instead of bonding the rails and grounding the track at intervals, the endless flexible rail is made to carry the current back to a fixed point, near that at which the feeder is tapped into the trolley wire. Thence it passes through the wheels to one of the fixed rail sections and thence back to the generator. The flexible rail is much larger than the current flowing through it requires, and was found to answer the purpose admirably.

The seating capacity of the road on the pier is 6,000 passengers at one time and at a speed of six miles ; 36,000 passengers will thus pass a given point in an hour. Considering that this is obtained from a 45-inch gauge, the capacity seems, indeed, marvelous. The trucks each weigh about 1,500 pounds and the platforms 1,200 pounds, or a total of trucks and platforms each of 2,700 pounds. There are 340 of these, making a total weight of train of 918,000 pounds. The motor trucks, of which there are ten, weigh 12,000 pounds each, thus making the total weight of the train 1,038,000 pounds or 5.19 tons.

To propel this train, 300 electrical H. P. are provided, as stated above.

The feat performed by this device is that 6,000 passengers—representing a dead load of 519 tons, or only 173 pounds per passenger—can be transported continuously by expending less than 200 H. P.

This road is reported to have carried at one time over 5,200 seated passengers, and

many more were walking on the platforms, bringing up the total number of passengers carried simultaneously to nearly 6,000. This number was carried with an expenditure of 120 electrical horse-power.

United States Geological Survey Column.—In the Mining Building there was a trophy constructed under the direction of Dr. David T. Day, Chief of Division of Mining Statistics and Technology, representing the mineral production of various fuels, ores, stones, metals, etc., in the United States. While the data used was not from any one year, all the quantities were taken from late years, so as to represent fairly the normal production. So as to illustrate the relative proportion in amount of the various substances taken from the earth, cubes were prepared which showed the volume won, each second of a year of 365 days, so that the quantities illustrated when multiplied by 31,536,000, would be equivalent to the annual output of each of the materials exhibited.

The base of the column was formed of a cube of bituminous coal weighing 3.3 gross tons, on which was a block of anthracite coal weighing 1.4 gross tons. Next came a cube of limestone, weighing .63 of a gross ton, and then a block of cannel coal, which was introduced as representing the equivalent of the volume of natural gas, this block weighing .4 of a ton. Surmounting the cannel coal was a case capable of holding 72 gallons of petroleum, and on this a half a ton cube of magnetic iron ore. Then followed granite, cement, salt, sandstone, phosphate rock, marble, gypsum, the volume of mineral waters, asphaltum, slate and other products. Cubes representing 12.8 pounds of lead, 9.4 pounds of copper, 5 pounds of zinc, 1.8 ounces of silver. .9 of an ounce of mercury, .25 of an ounce of antimony, .12 of an ounce of nickel, .067 ounce of aluminum, the same amount of tin, and 24 grains of gold, representing the metal produced from the ores of these minerals, occupied their proper places, with other mineral products such as pyrites, talc, barytes, borax, sulphur, asbestos, mica, etc.

The bituminous coal forming the base of the column represented a volume of 96 cubic feet, and it would have been impracticable to have shown the volume for a given interval of time greater than one second, for the first six products above named; but the interval selected was entirely too small to recognize some of the other products, for the cube of pure gold which surmounted the column contained but .006 cubic inch, and that of silver .34 cubic inch.

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